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EXECUTIVE SUMMARY

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Potential correlations between environmental or climate indices and fish stock abundance or year class strength (YCS) have previously been identified for New Zealand stocks of hoki, snapper, red cod, gemfish, rock lobster, and southern blue whiting. In this study we examined a wide selection of fish stock and environmental or climate indices to see if any other similar potential correlations could be found.

A total of 212 YCS and annual biomass indices were collated for 56 predominantly commercial finfish species, and 20 climate indices were estimated. The YCS estimates were derived from trawl survey time series, stock assessment models, and standardised catch per unit effort (CPUE) analyses. The biomass indices were derived from research trawl survey time series and standardised CPUE analyses. The fisheries indices had a length of between 5 and 31 years, and the climate indices between 8 and 33 years. Correlations and association tests between the fish YCS or biomass indices and the climate indices were made after predictor screening, restricting data to appropriate times of year, and adding appropriate time lags for YCS indices. Significant (at the 5% level) rank correlations were detected for 21 of the 48 YCS series (44%) and 86 of the 172 biomass series (50%). Significant (at the 5% level) association tests were detected for 34 YCS (71%) and 108 biomass series (63%).

Many of the correlations between climate and YCS or biomass indices were as strong as, or stronger than, those routinely reported in the published scientific literature. Potentially interesting correlations were found for several species and stocks. These included school shark, elephantfish, red gurnard, stargazer, hake, and tarakihi.

For the Chatham Rise and subantarctic, there were groups of species with markedly similar biomass trends, which in some cases were significantly correlated with climate. These included oblique banded rattail, Bollons’s rattail, and ling on the Chatham Rise, and banded rattail, Oliver’s rattail, dark ghost shark, and pale ghost shark in the subantarctic.

There was no clear evidence for any consistent changes in the YCS or relative abundance of species that were classified as ‘warm’ or ‘cold’ water species, and no consistent relationship between these and climate.

The correlations identified could nevertheless be spurious, and therefore further investigation is required to establish their validity. Priority should be given to extending existing time series of data, and estimating further appropriate environmental or climate indices on finer and more appropriate spatial or temporal scales. Future analyses might focus on the species identified above, and consider the uncertainty in YCS or biomass indices, other factors that may have affected abundance (e.g., fishing), smaller-scale temporal and spatial variability, and should include a robust statistical analysis of potential climate-fisheries relationships.

1. INTRODUCTION

The significance of climatic and environmental variability on fisheries productivity has been recognised for many years (e.g., Johnson & Smith 1965), but has grown in prominence more recently, especially with the recognition that human activities may be causing climate change on a global scale (IPCC 2007, Willis et al. 2007a).

In New Zealand, there is a rapidly growing body of scientific literature examining the relationship between fisheries and climate. McDowall (1992) considered the potential effect of climate change on freshwater fishes in New Zealand. The potential effect on New Zealand marine fisheries was the subject of a Climate Change Programme Impacts Working Group in 1989 (unpublished report 1989). The working group concluded that predictions of future regional climate were very uncertain, and they therefore made only general predictions for changes to the fisheries under a number of potential climate scenarios. The predicted impacts on fish populations were of two main types: (1) shifts in spatial distribution, and (2) changes to reproductive success and growth (i.e., productivity). The working group concluded that shifts in distribution would be more pronounced than changes in productivity, at least initially. This conclusion was consistent with more recent reports with a similar scope (e.g., Hobday et al. 2006).

The potential effects that climatic variability may have on fish are undoubtedly complex (Brander 2007). Being ectotherms ("cold blooded"), the physiological processes of fishes, such as their respiration and activity rate, growth and maturation, and sex determination, are directly influenced by temperature (Myers 2001, Devlin & Nagahama 2002, Pörtner et al. 2008). Changes in temperature have also been shown to change fish behaviour, such as migration routes (Stensholt 2001). There may also be indirect effects of climate change on fishes through changes in the availability of their food or habitat (Cushing 1990, Beaugrand et al. 2003, Otterson et al. 1994, Heath 2005). This can take place through, for example, changes in the location of productive frontal zones where the currents mix and their prey congregate (Zainuddin et al. 2008), the degree to which water columns mix because of wind direction and strength (Zeldis et al. 2005), or the composition of the plankton (Reid et al. 2001, Beaugrand 2004).

All fishes can tolerate a range of environmental conditions, although the limits of what they can tolerate depends on species, and potentially even on the population in question (Pörtner et al. 2008). Some species seem to be able to withstand and potentially adapt to a wide range of environmental and climatic conditions, at least for some of the time (Neat & Righton 2007). For the sustainability of fisheries on these species, overfishing may be a more immediate and greater problem, although more extreme environmental conditions certainly don't seem to help (O'Brien et al. 2000, Rothschild 2000, Brander 2005). When abrupt climatic changes take place they can often have a much more dramatic effect. These are sometimes referred to as "regime shifts". Such a regime shift took place in the North Sea in the late 1980s and early 1990s, at which time water currents and sea temperatures changed, and caused changes in the distribution and abundance of plankton, benthic invertebrates, and many species of fish (Reid et al. 2001, Beaugrand 2004, Dulvy et al. 2008). Some of these fish species were commercially exploited, so as a result the local fisheries also had to change (ICES 2004a, 2004b).

Despite the pervasive influence of the climate on fish life history, many studies only establish statistical correlations between large-scale environmental indices and fish abundance or distribution. As a result the mechanism behind the correlation is usually untested. In doing so, there is always a risk that the correlation was incorrect, or aliasing for something else, and the correlation might be misleading (Francis 2006). The environmental indices used in this way have been varied, for example temperature, light levels, salinity, oxygen levels, turbulence, and advection (e.g., Otterson et al. 2006, Stige et al. 2006, Roselund & Halldórsson 2007).

Nevertheless, identifying large-scale correlations is a first step towards identifying which species may be most at risk from environmental variability and climate change, knowing how many species in an area might be potentially vulnerable, the rate at which changes might occur, and perhaps which species might be at risk of local extinction (Perry et al. 2005, Rose 2005, Hannessonn 2007). This has obvious value for fisheries management, by allowing changes in fish stocks to be better understood, and allowing the various threats to fish stocks to be better evaluated (Schiermeier 2004).

1.1 Existing case studies in New Zealand

Hoki (*Macruronus novaezelandiae*) is one of the most valuable fisheries in New Zealand. In the early 2000s the hoki catch biomass declined, and the catch quota was substantially reduced. Although factors such as over-exploitation or intensive fishing on spawning aggregations may have contributed to the decline, poor recruitment for a period of 7 years (1995–2001) was a contributing factor. It is possible that climatic conditions in the mid 1990s to early 2000s may have been detrimental to recruitment. A relationship between climate and recruitment was found by Bull & Livingston (2001), but as the time series available for analysis increased the relationship became less clear (Francis et al. 2006). In the most recent study, Francis et al. (2006) used revised estimates of year class strength (YCS), and found that a generalised linear model (GLM) with YCS as the predictand and between 1 and 5 climate predictors, gave little or no predictive ability for YCS. The main reason for the change in result would appear to be the revision of the YCS estimates, as those used by Francis et al. (2006) were substantially different from those used by Bull & Livingston (2001).

Francis et al. (2006) suggested three reasons for their failure to detect a relationship between climate and hoki YCS: that the “right” environmental predictors were not included, that the environment-recruitment relationship may be more complex than described by the GLM, or that the environment-recruitment hypotheses were simply wrong. Additional reasons could be that the assumptions about stock structure could be wrong, or that the relationship between YCS and climate changed as the hoki stocks were depleted (Brander 2005).

There are a number of hypotheses for how climate may affect hoki recruitment. Bull & Livingston (2001) suggested stronger winds might cause increased upwelling in coastal areas, which might increase primary and secondary productivity and therefore food supply for hoki post-larvae, as well as facilitating the inshore transport of post-larvae towards the high food density areas; together these might improve growth and survival and lead to a higher YCS. They also suggested that the abundance of strong year classes might force weaker year classes to occupy more marginal habitat, which might exacerbate YCS variability. Francis et al. (2006) discussed the first hypothesis further, suggesting climate may also affect the timing of the water column mixing and subsequent productivity (a “match-mismatch hypothesis”, Cushing (1990)).

Beentjes & Renwick (2001) found that the recruitment of red cod (*Pseudophycis bachus*) was relatively high during colder years, which were associated with the El Niño events. The red cod fishery was dominated by new recruits, and therefore predicting recruitment was essentially the same as predicting potential fishery yield. A linear model relating catch to sea surface temperature has therefore been used to explain patterns in historical catches, and to forecast potential catches 1 year ahead, with some confidence (Beentjes & Renwick, pers.comm.).

Relatively high recruitment and faster growth rates of snapper (*Pagrus auratus*) in the Hauraki Gulf (snapper stock SNA 1) have been correlated with warmer conditions (Francis 1994a). The strength of the correlation between sea surface temperature (SST) and snapper year class strength depended on the months used for estimating SST, with the correlation increasing in December, peaking in February, and remaining high until June (Francis 1993).

This plateau corresponded with the end of larval settlement, settlement, and early post-settlement. SST was also found to affect larval duration, with higher temperatures reducing the time in the plankton, leading to earlier settlement and metamorphosis (Francis 1994b). Gilbert & Taylor (2001) found similar correlations between YCS and sea temperature for snapper stocks on the east coast of the North Island (SNA 2) and west coast South Island (SNA 7). Zeldis et al. (2005) found upwelling favourable winds caused increased incursions of shelf water into the Hauraki Gulf, which correlated with greater surface mixing, primary productivity, abundance of zooplankton, and higher survival of larval snapper. Zeldis et al. hypothesised that the higher survival rates of larval snapper might have been a response to improved feeding and growth conditions, and noted that this effect might be in addition to the direct temperature effects identified by Francis (1994b).

Fluctuations in the recruitment of gemfish (*Rexea solandri*) on the west coast of the South Island (WCSI), when classified as either “high” or “low” YCS, appeared to be negatively correlated with the winter frequency of occurrence of the south westerly wind flow, and positively correlated to the SST (Renwick et al. 1998). Increased southwesterly flow was consistent with lower SST, as the increased mixing would enhance heat flux out of the ocean. Renwick et al. (1998) hypothesised that the reduced recruitment in colder years was because of temperature sensitivity, as gemfish reached the southern limit of their range on the WCSI. They also noted that the pattern of YCS for gemfish was roughly opposite that for hoki YCS over the same time period.

Booth et al. (2000) developed a linear regression model that estimated rock lobster (*Jasus edwardsii*) puerulus settlement from two predictors, the Kidson “Trough” regime and a “High over the southeast” weather class. This implied that southerly stormy weather leads to increased settlement rates, but the mechanism involved remained unresolved, and no hypotheses were given. The authors concluded that the Wairarapa Counter Current might also have an effect on settlement.

Hanchet & Renwick (1999) found correlations between southern blue whiting (*Micromesistius australis*) YCS in the subantarctic and winter air pressure over the Campbell Plateau, the Kidson “Trough” index in summer, and the Hokitika – Chathams air pressure difference. A linear regression with these predictors had weak predictive ability, but an alternative analysis on the same data using YCS categories (“weak”, “medium”, and “strong”) proved to have a greater predictive ability, correctly classifying 76% of YCS in a cross-validation procedure. This model predicted YCS using the Auckland – Christchurch air pressure difference, SST near Campbell Island, and an index of the “Ridge across South Island” weather type. In general, the correlations suggested southern blue whiting YCS was greater in years with less stable, cooler ocean conditions.

Willis et al. (2007b) found negative correlations between southern blue whiting YCS in the subantarctic and the presence of a large high pressure system over the Campbell Plateau in winter, or a high pressure system over the northwest which would result in strong winds over the subantarctic in spring. They also found no significant correlation between YCS and SST, and hypothesised that higher YCS might result from rough winters with a high degree of water column mixing, following by relatively calm spring conditions. This supports the conclusions of Hanchet & Renwick (1999). Although the Willis et al. analyses showed a good correlation between some climatic variables and YCS, the linear regression models tended to underestimate very strong YCS and overestimate very weak YCS. Willis et al. suggested this was probably because the predictors described patterns over larger spatial scales than that at which the biological processes determining YCS operated. Alternatively, the relationship between climatic variables and YCS may become highly non-linear when climatic conditions outside the ‘norm’ are encountered.

There are a number of other studies which have less directly considered the climate effects on fisheries. Ayers et al. (2006) reviewed information for school sharks (*Galeorhinus australis*) around New Zealand, focusing on catch per unit effort (CPUE) indices of biomass. They hypothesised that there was a single population, which undertook north-south migrations depending on SST, with warmer years favouring a southerly movement. Taylor (2001) included a wind speed predictor in subantarctic orange roughy (*Hoplostethus atlanticus*) standardised CPUE models, after it was hypothesised that high wind speed led to low CPUE (and vice versa), in other words to a reduction in catchability; this was considered a particular problem for subantarctic fisheries. Although the wind speed predictor was statistically significant in the final CPUE model, it did not have any appreciable effect on the final CPUE index, and the model estimated relationship between CPUE and wind speed was not described. Neumann (2001) correlated SST with the distribution of dolphins (*Delphinus delphis*), which moved closer inshore during warmer years. Taylor (2002) described the invasion of the Chilean jack mackerel (*Trachurus murphyi*) into New Zealand waters in the mid 1980s, a species which subsequently dominated the jack mackerel fishery in some areas. The timing of this event coincided with increased frequency and magnitude of El Niño (Elizarov et al. 1993).

Determining potential correlations between fisheries and climate indices, rather than causal mechanisms, has been the focus of studies in New Zealand (and for most studies elsewhere). The investigations on snapper have come closest to understanding the causal mechanisms. The climate indices most frequently identified in the relationships were SST, pressure differences, wind strength and direction, and broad measures of climate (e.g., the Kidson regime indices; note that “regime” here has a climate-specific meaning, and is different from the ecological “regime shifts” described for the North Sea earlier). In addition, most of the New Zealand studies have focused on determining climate effects on YCS, rather than on distribution and catchability, even though climate effects on distribution might be more pronounced and therefore easier to detect. Francis et al. (2003) found significant evidence of inter-annual variation in catchability in trawl surveys and commercial fishery CPUE, and noted that this could be caused by changes in the distribution of the fish stocks, but considered the data series too short to allow examination of any causative factors.

1.2 Scope of the present study

The work described in this report was carried out under Ministry of Fisheries project SAM2005/02, with the specific objective “*To examine the possible effects of climate on fishery yields and abundance indices for commercial fisheries around New Zealand*”.

The approach taken was to search for possible correlations between a wide range of environmental and fisheries indices, as well as focus on some specific species and areas where data sets were most extensive and reliable, and where *a priori* we might most expect to see climate effects. We focused on coastal and middle depth finfish species. The wide range of stock indices (N=212) and climate indices (N=20) precluded the detailed examination of individual potential relationships; this is left to future studies.

The strength of this approach was that it examined a wide range of stocks. Some of these were of short-lived species; variability in stock biomass caused by climate sensitivity is more likely to be seen in highly productive and short-lived species, because such variability will be effectively hidden in the extended age-structure of longer-lived species. We also examined both YCS and catchability (distributional) correlations. Rapid changes in stock abundance are likely to be associated with major oceanographic changes, or fisheries exploitation (which may include catch levels and catchability effects). We also considered species with a more southern (cold water) or northern (warm water) distribution; we might expect the most obvious changes in biomass and productivity to be in stocks which are located near the limits of their geographic range, where the physiological limits are being approached.

There are clearly some limitations on the conclusions that we can draw from this approach. The scale over which the climate indices are measured is usually far removed from the scale over which most biological processes are taking place, and therefore possible causative factors behind correlations remain speculative. Also, the absence of a correlation does not necessarily mean that climate does not have a large effect on a stock. For example, we might not have the "right" climate indices, or the strength and nature of correlations might not be constant where large changes in species' abundance or life history have taken place (e.g., age structure, Longhurst (2002), Brander (2005)). Finally, many time series used in this study are relatively short, and must be interpreted with caution. Over a short time period, random variability might easily look like a trend, and might appear to be significantly correlated with climate (Francis 2006).

2. METHODS

2.1 Environmental data

The environmental and climate indices used here included most of those used in previous New Zealand climate and fisheries studies. We also included relatively new indices for sea surface height, and sea surface colour. Plots of all of the environmental and climate indices are given in Appendix A.

The environmental indices used in this study cover a range of time scales. The "Kidson weather types" and "Trenberth" indices both describe New Zealand-local climate variations. A significant fraction of the variability is associated with weather events and is hence unpredictable, or random, on monthly and longer time scales.

The Kidson weather types are defined on a 12-hourly basis, describing the daily sequence of weather over New Zealand in terms of a set of 12 types of weather maps, or surface wind flows. For this research, the monthly and longer frequency of occurrence of each of the types was used, to describe the character of a given month or season in terms of the representative types. Further to this, the 12 weather type frequencies may be grouped into the frequencies of occurrence of three weather "regimes", associated with westerly air flows, settled anticyclonic (reduced westerly) conditions, and with disturbed weather patterns.

The Trenberth indices describe monthly mean differences in mean sea-level pressure between various climate stations in the New Zealand region. Pressure differences are directly related to wind speed (perpendicular to the orientation of the pressure difference), hence the Trenberth indices encapsulate monthly mean wind flow direction and speed over New Zealand. As such, they are well correlated with some of the monthly Kidson weather type and regime frequencies, which also capture wind flows and pressure patterns around New Zealand (Table 1). Wind and pressure patterns affect surface ocean conditions through heat flux, degree of surface mixing, and upwelling on exposed coasts.

However, large-scale climate signals do modulate surface climate over New Zealand. The El Niño-Southern Oscillation (ENSO) cycle in the tropical Pacific has a strong influence on New Zealand. ENSO is described here by the Southern Oscillation Index (SOI), a measure of the difference in mean sea-level pressure between Tahiti (east Pacific) and Darwin (west Pacific). When the SOI is strongly positive, a La Niña event is taking place. New Zealand tends to experience reduced westerly winds and milder, more settled, anticyclonic weather. When the SOI is strongly negative, an El Niño event is taking place. New Zealand tends to experience increased westerly winds and cooler, less settled weather. Causal relationships of correlations of SOI with fisheries processes will be obscure, but probably related to one or more of the underlying ocean climate processes such as winds or temperatures.

The ENSO cycle is irregular, with El Niño events occurring every 3 to 7 years. There are no indications of long-term trends in the ENSO cycle (associated with anthropogenic climate change, or other causes), and future climate change projections give no strong indications of ENSO trends in future. The ENSO cycle is, however, naturally modulated by the Interdecadal Pacific Oscillation (IPO), a Pacific-wide reorganisation of the heat content of the upper ocean. The IPO changes from its positive to its negative polarity every 20 to 30 years. In the positive polarity, El Niño events tend to be more frequent and stronger, while in the negative polarity, El Niño events are weaker, and La Niña events are more prominent. Hence, New Zealand tends to experience 20–30 year periods of enhanced and reduced westerlies, with associated temperature and precipitation effects. There do not appear to be long-term trends in the behaviour of the IPO (or of ENSO) at present. However, paleoclimate evidence shows that over the past several thousand years, there have been centuries-long periods of little or no ENSO activity, and periods of strong and regular ENSO activity. The causes of such behaviour, and its implications for the future, are current research questions.

Sea surface temperature (SST) measures temperature at the very surface (less than 1 mm when measured from satellites). It may therefore not represent the temperature of the ocean as a whole. Sea surface height (SSH) is measured from satellites, and a better measure of temperature throughout the water column, with higher mean sea surface height indicating an increase in temperature. However, SST and SSH are quite closely correlated (Table 1). Sea temperatures are obviously influenced by weather conditions, and are reasonably well correlated with weather indices such as the SOI, and the Kidson “Blocking” regime (Table 1). Water temperatures directly affect fish, and have been found to be correlated with a variety of fisheries processes.

The level of primary productivity can be inferred from measurements of sea surface colour made from satellites. In coastal areas higher surface colour indicates higher chlorophyll concentrations (i.e., biomass of green algae), as well as the levels of suspended particles and dissolved organic matter. In oceanic areas the main source of colour is chlorophyll. Higher chlorophyll concentrations indicate higher ecosystem productivity. Higher primary productivity potentially has a more direct link to fisheries process than climate indices.

The weather type frequencies and pressure indices are both related to surface ocean conditions, largely through implied surface ocean heat fluxes. More settled, low-wind periods tend to be associated with increased sea temperatures, while the windier more disturbed flows tend to be associated with cooler seas. Coastal upwelling is modulated by along-shore wind flows, hence there are relationships between the various weather types and wind flows and upwelling on exposed coasts.

Further and more detailed climate and environmental indices of relevance to fisheries are being described for Ministry of Fisheries project ENV2007/04.

2.1.1 Kidson regime indices

The Kidson regimes (Kidson 2000) relate to the occurrence of different types of weather pattern over New Zealand. Kidson (2000) developed 12 weather patterns that describe the day to day variability in the atmospheric circulation and weather over the country. These were further grouped into three regimes, labelled Trough, Zonal, and Blocking.

The “Trough” Kidson regime is characterised by pressure troughs over and east of the country. It is linked with high rainfall, and below-normal temperatures in the south. The Trough regime typically brings wet, cool, and cloudy conditions to most of the country.

The “Zonal” Kidson regime is characterised by intense anticyclones north of 40° S, and strong westerlies to the south of the country. This produces an intensified westerly gradient south of the country, with highs to the north. The Zonal regime is linked with below-normal rainfall in the north and east, and above-normal temperatures in the south.

Table 1: Pearson correlation coefficients for paired correlations of annual mean estimates of the environmental indices.

																Kidson			chlorophyll			sst by FMA									ssh by FMA								
		Z1	Z2	Z3	Z4	M1	M2	M3	ZN	ZS	MZ1	MZ2	MZ3	MZ4	SOI	Tr	Zo	Bl	WCSI	SubA	Chat	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
	Z1	1																																					
	Z2	0.528	1																																				
	Z3	0.956	0.633	1																																			
	Z4	0.737	0.221	0.659	1																																		
	M1	-0.18	0.006	-0.13	-0.17	1																																	
	M2	0.487	0.319	0.422	0.774	-0.04	1																																
	M3	-0.21	-0.01	-0.15	-0.21	0.998	-0.1	1																															
	ZN	0.956	0.446	0.913	0.852	-0.17	0.573	-0.2	1																														
	ZS	0.782	0.71	0.907	0.34	-0.06	0.19	-0.07	0.656	1																													
	MZ1	0.242	-0.09	0.298	-0.1	0.01	-0.58	0.043	0.196	0.348	1																												
	MZ2	0.795	0.653	0.91	0.327	-0.05	0.099	-0.06	0.686	0.974	0.493	1																											
	MZ3	0.73	0.348	0.667	0.91	-0.07	0.913	-0.13	0.812	0.396	-0.22	0.35	1																										
	MZ4	0.792	0.176	0.696	0.839	-0.24	0.553	-0.27	0.884	0.375	0.084	0.397	0.728	1																									
	SOI	-0.42	-0.16	-0.3	-0.49	0.023	-0.48	0.05	-0.43	-0.11	0.257	-0.06	-0.51	-0.41	1																								
Kidson	Tr	0.306	-0.36	0.2	0.682	-0.18	0.395	-0.2	0.439	-0.08	-0	-0.09	0.509	0.621	-0.24	1																							
	Zo	0.494	0.787	0.535	0.134	0.013	0.229	1E-04	0.369	0.607	-0.02	0.581	0.27	0.088	-0.31	-0.51	1																						
	Bl	-0.8	-0.38	-0.73	-0.85	0.178	-0.64	0.214	-0.82	-0.5	0.022	-0.47	-0.8	-0.74	0.554	-0.56	-0.42	1																					
Chlorophyll	WCSI	0.623	0.415	0.585	0.647	-0.16	0.545	-0.17	0.626	0.377	-0.19	0.309	0.622	0.4	-0.86	0.341	0.303	-0.7	1.00																				
	SubA	-0.2	-0.68	-0.4	0.228	-0.4	0.448	-0.41	-0.1	-0.71	-0.77	-0.81	0.324	0.2	-0.33	0.629	-0.7	-0.31	-0.02	1.00																			
	Chat	-0.32	0.201	-0.2	-0.63	0.111	-0.66	0.131	-0.31	0.005	0.684	0.228	-0.6	-0.45	0.73	-0.6	0.485	0.44	-0.38	-0.38	1.00																		
sst by FMA	1	-0.13	0.266	0.053	-0.43	0.043	-0.4	0.065	-0.21	0.314	0.257	0.336	-0.39	-0.39	0.561	-0.48	0.098	0.416	-0.34	-0.79	0.45	1																	
	2	-0.21	0.232	-0.05	-0.37	0.01	-0.4	0.033	-0.25	0.161	0.107	0.162	-0.43	-0.33	0.449	-0.3	0.034	0.281	-0.78	-0.38	0.34	0.837	1																
	3	-0.48	-0.16	-0.32	-0.49	0.109	-0.3	0.125	-0.49	-0.09	-0.05	-0.1	-0.45	-0.5	0.513	-0.33	-0.2	0.539	-0.84	-0.07	0.42	0.56	0.515	1															
	4	-0.45	-0.15	-0.3	-0.57	0.057	-0.5	0.085	-0.49	-0.04	0.103	-0.03	-0.59	-0.5	0.613	-0.34	-0.22	0.573	-0.88	-0.10	0.46	0.701	0.73	0.88	1														
	5	-0.47	-0.16	-0.33	-0.52	0.032	-0.3	0.049	-0.51	-0.09	-0.07	-0.12	-0.43	-0.57	0.402	-0.31	-0.15	0.48	-0.91	0.13	0.37	0.577	0.589	0.88	0.8	1													
	6	-0.2	-0.25	-0.17	-0.34	0.03	-0.14	0.038	-0.29	-0.01	-0.02	-0.06	-0.2	-0.3	0.054	-0.14	-0.14	0.283	-0.57	0.64	-0.07	0.272	0.23	0.61	0.58	0.72	1												
	7	-0.52	-0.11	-0.35	-0.65	0.169	-0.45	0.194	-0.57	-0.07	0.066	-0.06	-0.58	-0.6	0.645	-0.44	-0.19	0.647	-0.79	-0.27	0.45	0.756	0.684	0.89	0.9	0.87	0.53	1											
	8	-0.41	0.029	-0.23	-0.63	0.195	-0.51	0.223	-0.48	0.057	0.148	0.07	-0.6	-0.53	0.614	-0.47	-0.08	0.572	-0.70	-0.48	0.42	0.878	0.846	0.77	0.89	0.75	0.44	0.93	1										
	9	-0.32	0.106	-0.13	-0.56	0.107	-0.46	0.132	-0.39	0.159	0.176	0.179	-0.52	-0.52	0.631	-0.52	-0.01	0.557	-0.47	-0.71	0.50	0.951	0.795	0.74	0.83	0.7	0.35	0.89	0.95	1									
ssh by FMA	1	-0.24	0.197	0.062	-0.44	-0.05	-0.19	-0.04	-0.27	0.39	0.033	0.345	-0.31	-0.43	0.687	-0.43	-0.03	0.648	-0.90	-0.35	0.45	0.797	0.757	0.9	0.85	0.9	0.63	0.88	0.78	0.81	1.00								
	2	-0.34	0.236	-0.06	-0.54	-0.07	-0.34	-0.06	-0.39	0.292	0.022	0.262	-0.5	-0.49	0.705	-0.52	0.028	0.718	-0.91	-0.25	0.31	0.823	0.878	0.9	0.92	0.87	0.59	0.88	0.86	0.85	0.94	1.00							
	3	-0.36	0.278	-0.13	-0.53	-0.04	-0.15	-0.04	-0.44	0.226	-0.22	0.142	-0.4	-0.52	0.592	-0.49	0.119	0.584	-0.90	-0.06	0.45	0.636	0.709	0.84	0.81	0.89	0.69	0.79	0.71	0.69	0.90	0.92	1.00						
	4	-0.38	0.293	-0.12	-0.55	-0.05	-0.23	-0.04	-0.44	0.225	-0.13	0.179	-0.45	-0.54	0.648	-0.54	0.092	0.674	-0.94	-0.13	0.52	0.719	0.797	0.88	0.88	0.89	0.64	0.84	0.78	0.76	0.93	0.96	0.98	1.00					
	5	-0.4	0.261	-0.14	-0.61	-0.03	-0.27	-0.02	-0.47	0.226	-0.11	0.165	-0.49	-0.55	0.681	-0.52	0.064	0.685	-0.92	-0.11	0.48	0.677	0.75	0.88	0.86	0.91	0.67	0.84	0.76	0.73	0.93	0.94	0.98	0.98	1.00				
	6	-0.46	0.229	-0.26	-0.63	-0.03	-0.27	-0.02	-0.55	0.102	-0.21	0.024	-0.52	-0.59	0.634	-0.49	0.033	0.669	-0.81	-0.10	0.41	0.57	0.676	0.82	0.8	0.86	0.64	0.75	0.66	0.62	0.86	0.88	0.95	0.93	0.97	1.00			
	7	-0.42	0.235	-0.13	-0.61	0.013	-0.29	0.024	-0.45	0.241	-0.03	0.215	-0.49	-0.56	0.739	-0.54	0.041	0.734	-0.94	-0.18	0.57	0.763	0.819	0.94	0.91	0.92	0.63	0.92	0.84	0.81	0.96	0.96	0.94	0.97	0.97	0.91	1.00		
	8	-0.35	0.222	-0.04	-0.55	-0.02	-0.26	-0.01	-0.38	0.312	0.018	0.286	-0.43	-0.51	0.737	-0.51	0.018	0.705	-0.93	-0.26	0.60	0.788	0.799	0.93	0.89	0.91	0.61	0.92	0.82	0.82	0.98	0.95	0.93	0.96	0.96	0.89	0.99	1.00	
	9	-0.3	0.267	0.026	-0.53	-0.02	-0.26	-0.01	-0.33	0.381	0.047	0.352	-0.4	-0.49	0.714	-0.51	0.048	0.686	-0.89	-0.35	0.63	0.81	0.783	0.92	0.87	0.89	0.6	0.91	0.82	0.84	0.98	0.95	0.92	0.95	0.95	0.87	0.98	1.00	1.00

The “Blocking” Kidson regime is characterised by pressure highs lying to the south and east, and is linked with a southwest-northeast contrast in rainfall (below normal in SW, above normal in NE) and above-normal temperatures, except on the east coast of both islands.

These regimes have shown a seasonal pattern, with reduced frequency of the Zonal regime and greater frequency of the Blocking regime over summer. The mean persistence of any regime tends to be about 1–1.8 days, but individual regimes may dominate the weather for 2–4 weeks. It should be noted that the Kidson regimes are not that clearly defined, and within each the variation in climatic elements is large. As a result, in climate studies they are considered only a qualitative measure. The frequencies of these are not strongly linked to larger scale indices, such as the SOI, though the ENSO cycle does modulate weather sequences over New Zealand to a degree. The Kidson indices were supplied as the percentage of days in each month in each of the three Kidson regime types (Trough, Zonal, Blocking).

2.1.2 Mean sea-level pressure indices

These indices measure mean sea level pressure differences, which by the geostrophic relationship are proportional to the mean wind speed in wind direction perpendicular to that of the line between the two measurement points. The indices used in this study are the Trenberth indices (Trenberth 1976), and the SOI (e.g. Mullan 1995) (Table 2).

The Trenberth indices refer to specific areas of New Zealand, and are just differences in mean sea level pressure between the sites listed. For example, Z1 is the monthly mean sea level pressure difference of Auckland minus Christchurch. They are normalised to be unit standard deviation departures from a mean of zero. By geostrophic balance, the pressure difference between two points is a direct proxy for the average strength of the wind perpendicular to that pressure difference, in the region between the points. So, Z1 measures (approximately) the strength of the westerly wind over the region between Auckland and Christchurch, since the pressure difference is roughly north-south, so the geostrophic wind is roughly east-west. The "Z" indices are for Zonal (i.e., westerly) wind, as they are mostly north-south differences, and are well correlated. The "M" indices are for Meridional (i.e., southerly) wind as they are mostly east-west differences. The "MZ" indices measure winds in the northwest-southeast and southwest-northeast directions. The correlation between the various Trenberth indices is shown in Table 1. The Trenberth indices were available for 1973–2006.

The SOI is the normalised mean sea surface pressure difference between Tahiti and Darwin and is related to the strength of the trade winds in the southern hemisphere tropical Pacific. Values of the SOI above 10 indicate La Niña conditions, associated on average with more northeasterlies and warmer temperatures over New Zealand, whereas those below -10 indicate El Niño, associated on average with enhanced southwesterlies and cooler temperatures over New Zealand. The Trenberth index MZ3 is therefore correlated with the SOI but is defined locally over New Zealand rather than in the Tropics.

There was one missing value for M1, which was replaced with the mean for the month over all other years.

2.1.3 Sea surface temperature, sea surface height, and primary productivity

Sea surface temperature, sea surface height, and sea surface chlorophyll indices were derived from satellite observations (Uddstrom & Oien 1999). Monthly sea surface temperature (SST) was available on a 1° by 1° grid from 160.5° E to 172.5° W and 30.5° S to 58.5° S, for 1973–2006. Monthly sea surface height (SSH) was available on a 1° by 1° grid from 160.5° E to 172.5° W and 30.5° S to 58.5° S, for 1992–2006, and was correlated with SST (Table 1).

Monthly mean and anomaly values of chlorophyll were available for three regions, the west coast South Island (WCSI), SubAntarctic (SubA), and Chatham Rise (Chat), for 1997–2004.

Table 2: The Trenberth and SOI indices, and the mean wind direction and area to which they apply, with the Fisheries Management Area (FMA) and area to which they were applied in this study (Chat, Chatham Rise; TB, Tasman Bay; WCSI, west coast South Island; SubA, SubAntarctic).

Index	Mean wind direction and area	FMA	Area
Z1 : Auckland - Christchurch	Westerly, North Island & northern South Island	1,2,3,4,7,8,9	Chat, TB, WCSI
Z2 : Christchurch-Campbell	Westerly, southern South Island & sub-Antarctic	3,4,5,6,7	Chat, WCSI, SubA
Z3 : Auckland-Invercargill	Westerly, whole of New Zealand	1-9	Chat, TB, WCSI, SubA
Z4 : Raoul-Chatham	Westerly, 30-45S	1,2,3,4,7,8,9	Chat, TB, WCSI
M1 : Hobart-Chatham	Southerly, Tasman/New Zealand/Chatham Rise	1,2,3,4,7,8,9	Chat, TB, WCSI
M2 : Hokitika-Chatham	Southerly, New Zealand/Chatham Rise	2,3,4	Chat
M3 : Hobart-Hokitika	Southerly, Tasman Sea	7,8,9	TB
MZ1 : Gisborne-Hokitika	Northwesterly, central New Zealand	3,4,7	Chat, WCSI, TB
MZ2 : Gisborne-Invercargill	Northwesterly, southern North Island and South Island	3,5,6,7	WCSI,SubA
MZ3 : New Plymouth-Chatham	Southwesterly, central New Zealand	2,3,4,7,8	Chat,WCSI, TB
MZ4 : Auckland-New Plymouth	Westerly, northern North Island	1,2,8,9	none
ZN : Auckland-Kelburn	Westerly, North Island	1,2,8,9	TB
ZS : –Kelburn-Invercargill	Westerly, South Island	3,4,5,6,7	Chat, WCSI, TB, SubA
SOI : Tahiti-Darwin	Northeast/southwest	All	all

2.2 Fisheries data

The fisheries data fell into two groups:

1. Indices of year class strength (YCS) estimated from:
    a. Stock assessment model outputs
    b. Research trawl survey estimates of individual cohort abundance
    c. Commercial catch per unit effort (CPUE) analyses, where it could be assumed that the fishery was exploiting only a single cohort (e.g., arrow squid)
2. Indices of relative biomass estimated from:
    a. Research trawl surveys
    b. Commercial CPUE analyses

Tests for correlations between climate and YCS indices effectively assumed that climate can influence spawning success or juvenile mortality rates. Tests for correlations between climate and biomass indices effectively assumed that climate can influence catchability. No assumption was made about the relationship between YCS and biomass. In some instances the same set of observational data could be used several times, for example the Chatham Rise middle-depths trawl survey provided three estimates for hake; 3+ YCS, 4+ YCS, and total biomass (all age classes).

The estimates of year class strength (YCS) were taken either from the MFish Stock Assessment Plenary Reports (e.g., Ministry of Fisheries Science Group 2007), or from published Fisheries Assessment Reports (FARs). Most of the YCS estimates were from stock assessment models (HOKe and HOKw), others were cohort specific estimates from trawl survey (e.g., HOK.Chat) or surveys or fisheries which were dominated by a single year class (e.g., WCSI.ASQ) (Table 3). In the last two cases, it was usually necessary to offset the year of the index so that it corresponded to the birth year. YCS estimates from stock assessment models are output as the birth year, and so no year offset was necessary. No allowance was made for potential ageing errors in estimating YCS.

For hake, ling, and barracouta, YCS estimates were available for the same year class in subsequent years, e.g., the relative YCS of a cohort was measured at age 3+ in year 1, and then again at age 4+ in year 2. In these cases, the estimates were combined to obtain a single set of YCSs. This combination was done in three steps: (1) the abundance estimates for the older age group were scaled so that they had the same mean value as those for the younger age group (where the means were calculated just for the birth years in which the estimates from the two groups overlapped); (2) a mean YCS was calculated for every birth year with at least one estimate; and (3) these mean YCSs were scaled to average 1. Note that the scaling between age groups will be poor for the two barracouta instances (where there was only one year of overlap), but should be much better for hake and ling, with 7 years of overlap in each case. The indices derived in this way were BAR7TB, BAR7WCm HAK5+6 and LIN5+6 (Table 3).

The abundance indices were all expressed in terms of biomass. Biomass indices from trawl surveys and commercial CPUE in the same area may not necessarily show the same patterns, as they could be monitoring different parts of the population. Commercial vessels usually spatially and temporally target their fishing effort, whereas trawl surveys are designed to sample fish populations at random (in a statistical sense).

The biomass data were obtained from three main sources: the MFish Fisheries Plenary Report (Ministry of Fisheries Science Group 2007); standardised CPUE indices calculated for species in the Adaptive Management Programme (Paul Starr, pers.comm., May 2007); and estimates from MFish trawl surveys published in FARs, up to October 2006. Where multiple AMP CPUE indices were available, only those considered most reliable and plausible were used in the analyses (Paul Starr, pers.comm., May 2007). The trawl survey indices included unpublished estimates for some of the less abundant or non-commercial species thought to be usefully sampled by a bottom trawl. The precision of the biomass estimates (although collated) were not used in the analyses. Eight trawl surveys were included (Table 4). Indices derived from these trawl surveys were prefixed with the survey label, and had the *type* “trawl” (Tables 3 & 4).

A spawning season (autumn, winter, summer, spring) was defined for each species, where data were available (Table 3). Sources included the Ministry of Fisheries Plenary Report and website on status of the stocks (http://www.fish.govt.nz/en-nz/SOF/default.htm in June 2008), as well as published information summarising trawl surveys and Ministry of Fisheries observer records (Hurst et al. 2000, O’Driscoll et al. 2003). These seasons were used to determine the appropriate season over which the climatic indices needed to be averaged in order to relate them to the YCS indices. Plots of all of the YCS and biomass indices are given in Appendix B.

Table 3: New Zealand species considered for this study. Data Series, the name of the index; Type, YCS, trawl survey, or commercial CPUE; Polygon, the grid area used for SST and SSH estimates; Year offset, the adjustment done to the biomass index year when compared to the climate index; Main spawn season (sum, Jan-Mar; aut, Apr-Jun; win, Jul-Sep; spr, Oct-Nov), Range is a broad measure of the species' range, and can be used to identify more northern and southern species (NI, North Island; SI, South Island; Both, NI & SI; SA, SubAntarctic; All, NI & SI & SA); Age refers to longevity (S, <6 years; M, 6 to <15 years; L, 15 to <30 years; VL, 30 or more years; U, unknown). Each data series is labelled with the species (e.g., ASQ), and area (e.g., TBGB, Tasman Bay & Golden Bay), and where appropriate also with the year class (e.g., 1+ in BAR1.WCSI); "SubA.HAKa" includes Puysegur, "SubA.HAK" does not). The hake and ling 3+ and 4+ indices, and the red cod trawl and CPUE indices, were used as both as YCS and biomass indices (e.g., "Chat.HAK3")., in the case of red cod this was because the fishery was believed to be dominated by new recruits. For snapper the "SNA1" index refers to YCS, the "SNA1cpue" index refers to commercial CPUE.

Code	Common name	Data Series	Type	Polygon	Year offset	Main spawn season	Range	Age
ASQ	Arrow squid	TBGB.ASQ	TRAWL	TB	-1	win/spr	Both	S
		WCSI.ASQ	TRAWL	WCSI	-1	win/spr		
BAR	Barracouta	BAR7TB	YCS (0+)	TB	-1	win/spr	Both	M
		BAR7WC	YCS (1+)	WCSI	-2	win/spr		
		BAR1.WCSI	YCS (1+)	WCSI	-2	win/spr		
		BAR2.WCSI	YCS (2+)	WCSI	-3	win/spr		
		BAR0.TB	YCS (0+)	TB	-1	win/spr		
		BAR1.TB	YCS (1+)	TB	-2	win/spr		
		FMA8.BAR	TRAWL	FMA8	0	win/spr		
		FMA9.BAR	TRAWL	FMA9	0	win/spr		
		TBGB.BAR	TRAWL	TB	0	win/spr		
		WCSI.BAR	TRAWL	WCSI	0	win/spr		
		BAR1	CPUE	FMA3	0	win/spr		
		BAR5	CPUE	FMA56	0	win/spr		
BBE	Banded bellowsfish	Chat.BBE	TRAWL	CR	0	all	All	U
BCO	Blue cod	TBGB.BCO	TRAWL	TB	0	win/spr	Both	L
		BCO5	CPUE	FMA56	0	win/spr		
CAR	Carpet shark	TBGB.CAR	TRAWL	TB	0	all	Both	U
		WCSI.CAR	TRAWL	WCSI	0	all		
CAS	Oblique banded rattail	Chat.CAS	TRAWL	CR	0	all	SI	U
		SubA.CAS	TRAWL	SubA	0	all		
CBI	Two saddle rattail	Chat.CBI	TRAWL	CR	0	all	Both	U
CBO	Bollons's rattail	Chat.CBO	TRAWL	CR	0	all	Both	U
CFA	Banded rattail	Chat.CFA	TRAWL	CR	0	all	Both	U
		SubA.CFA	TRAWL	SubA	0	all		
COL	Oliver's rattail	Chat.COL	TRAWL	CR	0	all	Both	U
		SubA.COL	TRAWL	SubA	0	all		
CUC	Cucumber fish	WCSI.CUC	TRAWL	WCSI	0	all	Both	U
ELE	Elephantfish	WCSI.ELE	TRAWL	WCSI	0	all	SI	M
		ELE3	CPUE	FMA3	0	all		
		ELE5	CPUE	FMA56	0	all		
ERA	Electric ray	TBGB.ERA	TRAWL	TB	0	all	Both	U
		WCSI.ERA	TRAWL	WCSI	0	all		
ESO	N.Z. sole	TBGB.ESO	TRAWL	TB	0	win/spr	Both	U
		WCSI.ESO	TRAWL	WCSI	0	win/spr		
FHD	Deepsea flathead	Chat.FHD	TRAWL	CR	0	all	All	U
FRO	Frostfish	WCSI.FRO	TRAWL	WCSI	0	sum/aut/win	Both	M
GMU	Grey mullet	GMU1	CPUE	FMA19	0	spr/sum	Both	M
GSH	Dark ghost shark	Chat.GSH	TRAWL	CR	0	all	Both	U
		SubA.GSH	TRAWL	SubA	0	all		
		WCSI.GSH	TRAWL	WCSI	0	all		
GSP	Pale ghost shark	Chat.GSP	TRAWL	CR	0	all	All	U
		SubA.GSP	TRAWL	SubA	0	all		
GUR	Red gurnard	GUR1	YCS (1+)	FMA1	-1	spr/sum	Both	L
		GUR7TB	YCS (1+)	TB	-1	spr/sum		
		GUR7WC	YCS (1+)	FMA7WCSI	-1	spr/sum		
		GUR9	YCS (1+)	FMA9	-1	spr/sum	Both	L
		BoP.GUR	TRAWL	FMA1	0	spr/sum		
		FMA8.GUR	TRAWL	FMA8	0	spr/sum		
		FMA9.GUR	TRAWL	FMA9	0	spr/sum		

Table 3 (cont.)

Code	Common name	Data Series	Type	Polygon	Year offset	Main spawn season	Range	Age
		HG.GUR	TRAWL	FMA1	0	spr/sum		
		TBGB.GUR	TRAWL	TB	0	spr/sum		
		WCSI.GUR	TRAWL	WCSI	0	spr/sum		
		GUR1	CPUE	FMA19	0	spr/sum		
		GUR2	CPUE	FMA2	0	spr/sum		
		GUR3	CPUE	FMA3456	0	spr/sum		
HAK	Hake	HAK1235689	YCS (0)	FMA56	0	win/spr/sum	All	L
		HAK4	YCS (0)	FMA34	0	win/spr/sum		
		HAK5+6	YCS (3+)	FMA56	-3	win/spr/sum		
		HAK7WC	YCS (1+)	FMA7WCSI	-2	win/spr/sum		
		HAK3.SubA	YCS (3+)	FMA56	-3	win/spr/sum		
		HAK4.SubA	YCS (4+)	FMA56	-4	win/spr/sum		
		Chat.HAK3	YCS (3+)	CR	-3	win/spr/sum		
		Chat.HAK4	YCS (4+)	CR	-4	win/spr/sum		
		Chat.HAK	TRAWL	CR	0	win/spr/sum		
		Chat.HAK3	TRAWL	CR	0	win/spr/sum		
		Chat.HAK4	TRAWL	CR	0	win/spr/sum		
		SubA.HAK	TRAWL	SubA	0	win/spr/sum		
		SubA.HAKa	TRAWL	SubA	0	win/spr/sum		
		WCSI.HAK	TRAWL	WCSI	0	win/spr/sum		
		HAK1	CPUE	FMA1235689	0	win/spr/sum		
		HAK4cpue	CPUE	FMA4	0	win/spr/sum		
HAP	Hapuku	WCSI.HAP	TRAWL	WCSI	0	win	Both	VL
HOK	Hoki	HOKe	YCS (0)	CR	0	win/spr	All	L
		HOKw	YCS (0)	WCSI	0	win/spr		
		HOK.chat	YCS (1+)	CR	-2	win/spr		
		Chat.HOK	TRAWL	CR	0	win/spr		
		SubA.HOK	TRAWL	SubA	0	win/spr		
		WCSI.HOK	TRAWL	WCSI	0	win/spr		
JAV	Javelinfish	Chat.JAV	TRAWL	CR	0	all	All	U
		SubA.JAV	TRAWL	SubA	0	all		
JDO	John dory	JDO9	YCS (1+)	FMA9	-1	sum/aut	Both	M
		BoP.JDO	TRAWL	FMA1	0	sum/aut		
		BoP.JDO1	TRAWL	FMA1	0	sum/aut		
		FMA8.JDO	TRAWL	FMA8	0	sum/aut		
		FMA9.JDO	TRAWL	FMA9	0	sum/aut		
		HG.JDO	TRAWL	FMA1	0	sum/aut		
		TBGB.JDO	TRAWL	TB	0	sum/aut		
		WCSI.JDO	TRAWL	WCSI	0	sum/aut		
JMD	Jack mackerel (*declivis*)	TBGB.JMD	TRAWL	TB	0	spr/sum	Both	L
		WCSI.JMD	TRAWL	WCSI	0	spr/sum		
JMM	Jack mackerel (*murphyi*)	WCSI.JMM	TRAWL	WCSI	0	sum/aut	Both	VL
JMN	Jack mackerel (*novaezelandiae*)	TBGB.JMN	TRAWL	TB	0	spr/sum	Both	L
		WCSI.JMN	TRAWL	WCSI	0	spr/sum		
LDO	Lookdown dory	Chat.LDO	TRAWL	CR	0	aut/win	All	VL
		SubA.LDO	TRAWL	SubA	0	aut/win		
LEA	Leatherjacket	BoP.LEA	TRAWL	FMA1	0	all	Both	M
		HG.LEA	TRAWL	FMA1	0	all		
		TBGB.LEA	TRAWL	TB	0	all		
		WCSI.LEA	TRAWL	WCSI	0	all		
LIN	Ling	LIN5+6	YCS (3+)	FMA56	-3	spr	All	VL
		LIN34	YCS (0)	FMA34	0	spr		
		LIN56	YCS (0)	FMA56	0	spr		
		LIN7WC	YCS (0)	FMA7WCSI	0	win/spr		
		LIN3.SubA	YCS (3+)	FMA56	-3	spr		
		LIN4.SubA	YCS (4+)	FMA56	-4	spr		
		Chat.LIN3	YCS (3+)	CR	-3	spr		
		Chat.LIN4	YCS (4+)	CR	-4	spr		
		Chat.LIN	TRAWL	CR	0	spr		
		Chat.LIN3	TRAWL	CR	0	spr		
		Chat.LIN4	TRAWL	CR	0	spr		
		SubA.LIN	TRAWL	SubA	0	spr		
		WCSI.LIN	TRAWL	WCSI	0	win/spr		

Table 3 (cont.)

Code	Common name	Data Series	Type	Polygon	Year offset	Main spawn season	Range	Age
		LIN1	CPUE	FMA19	0	spr		
		LIN2	CPUE	FMA2	0	spr		
		LIN3&4	CPUE	FMA34	0	spr		
		LIN5&6	CPUE	FMA56	0	spr		
		LIN6	CPUE	FMA6	0	spr		
		LIN7	CPUE	FMA7WCSI	0	win/spr		
LSO	Lemon sole	TBGB.LSO	TRAWL	TB	0	win/spr	All	U
		WCSI.LSO	TRAWL	WCSI	0	win/spr		
NSD	Northern spiny dogfish	WCSI.NSD	TRAWL	WCSI	0	aut/win	NI	L
RBY	Rubyfish	RBY2	CPUE	FMA2	0	all	Both	VL
RCO	Red cod	RCO3-6	YCS (1+)	FMA3456	-1	win/spr	Both	M
		RCO7	YCS (1+)	FMA7WCSI	-1	win/spr		
		RCO7TB	YCS (1+)	TB	-2	win/spr		
		RCO7WC	YCS (1+)	WCSI	-2	win/spr		
		TBGB.RCO	TRAWL	TB	0, -1	win/spr		
		WCSI.RCO	TRAWL	WCSI	0, -1	win/spr		
		RCO3	CPUE	FMA3456	0, -1	win/spr		
		RCO7cpue	CPUE	FMA7WCSI	0, -1	win/spr		
RIB	Ribaldo	Chat.RIB	TRAWL	CR	0	aut/win	All	U
		SubA.RIB	TRAWL	SubA	0	aut/win		
RSK	Rough skate	TBGB.RSK	TRAWL	TB	0	spr/sum	All	M
		WCSI.RSK	TRAWL	WCSI	0	spr/sum		
RSN	Red snapper	None	-	-	-	-	-	-
SBW	Southern blue whiting	SubA.SBW	TRAWL	SubA	0	win/spr	SI & SA	L
		SBW6B	CPUE	SubA	0	win/spr		
		SBW6I	CPUE	SubA	0	win/spr		
SCG	Scaly gurnard	TBGB.SCG	TRAWL	TB	0	all		U
		WCSI.SCG	TRAWL	WCSI	0	all		
SCH	School shark	FMA8.SCH	TRAWL	FMA8	0	spr/sum	Both	VL
		FMA9.SCH	TRAWL	FMA9	0	spr/sum		
		TBGB.SCH	TRAWL	TB	0	spr/sum		
		WCSI.SCH	TRAWL	WCSI	0	spr/sum		
		SCH1	CPUE	FMA19	0	spr/sum		
		SCH3	CPUE	FMA3	0	spr/sum		
		SCH5	CPUE	FMA56	0	spr/sum		
		SCH7	CPUE	FMA7WCSI	0	spr/sum		
		SCH8	CPUE	FMA8	0	spr/sum		
SDO	Silver dory	Chat.SDO	TRAWL	CR	0	all	All	U
		WCSI.SDO	TRAWL	WCSI	0	all		
SFL	Sand flounder	HG.SFL	TRAWL	FMA1	0	win/spr	Both	U
		TBGB.SFL	TRAWL	TB	0	win/spr		
SKI	Gemfish	SKI1+9	YCS (0)	FMA19	0	win	Both	L
		SKI7+8	YCS (0)	FMA78	0	win		
		WCSI.SKI	TRAWL	WCSI	0	win		
		SKI1	CPUE	FMA19	0	win		
		SKI2	CPUE	FMA2	0	win		
SNA	Snapper	SNA1	YCS (0)	FMA1	0	spr/sum	Both	VL
		SNA8+9	YCS (0)	FMA89	0	spr/sum		
		SNA9	YCS (0)	FMA9	0	spr/sum		
		BoP.SNA	TRAWL	FMA1	0	spr/sum		
		BoP.SNA2	TRAWL	FMA2	0	spr/sum		
		FMA8.SNA	TRAWL	FMA8	0	spr/sum		
		FMA9.SNA	TRAWL	FMA9	0	spr/sum		
		HG.SNA	TRAWL	FMA1	0	spr/sum		
		SNA1cpue	CPUE	FMA1	0	spr/sum		
SND	Shovelnose dogfish	Chat.SND	TRAWL	CR	0	all	All	U
SPD	Spiny dogfish	FMA8.SPD	TRAWL	FMA8	0	win	Both	L
		FMA9.SPD	TRAWL	FMA9	0	win		
		SubA.SPD	TRAWL	SubA	0	win		
		TBGB.SPD	TRAWL	TB	0	win		
		WCSI.SPD	TRAWL	WCSI	0	win		
		Chat.SPD	TRAWL	CR	0	win		
		SPD3	CPUE	FMA3	0	win		

Table 3 (cont.)

Code	Common name	Data Series	Type	Polygon	Year offset	Main spawn season	Range	Age
		SPD5	CPUE	FMA5	0	win		
		SPD6	CPUE	FMA6	0	win		
		SPD7	CPUE	FMA7WCSI	0	win		
SPE	Sea perch	Chat.SPE	TRAWL	CR	0	all	Both	VL
		TBGB.SPE	TRAWL	TB	0	all		
		WCSI.SPE	TRAWL	WCSI	0	all		
		SPE3	CPUE	FMA3	0	all		
SPO	Rig	FMA8.SPO	TRAWL	FMA8	0	spr	Both	L
		FMA9.SPO	TRAWL	FMA9	0	spr		
		TBGB.SPO	TRAWL	TB	0	spr		
		WCSI.SPO	TRAWL	WCSI	0	spr		
		SPO3	CPUE	FMA3456	0	spr		
		SPO7	CPUE	FMA7WCSI	0	spr		
		SPO8	CPUE	FMA8	0	spr		
SSK	Smooth skate	WCSI.SSK	TRAWL	WCSI	0	all	All	L
STA	Stargazer	TBGB.STA	TRAWL	TB	0	all	All	L
		WCSI.STA	TRAWL	WCSI	0	all		
		STA3	CPUE	FMA3	0	all		
		STA4	CPUE	FMA4	0	all		
		STA5	CPUE	FMA56	0	all		
		STA7	CPUE	FMA7WCSI	0	all		
SWA	Silver warehou	SWA7TB	YCS (1+)	TB	-2	win/spr	All	L
		SWA7WC	YCS (1+)	WCSI	-2	win/spr		
		TBGB.SWA	TRAWL	TB	0	win/spr		
		WCSI.SWA	TRAWL	WCSI	0	win/spr		
TAR	Tarakihi	TAR7TB	YCS (2+)	TB	-2	sum/aut	Both	VL
		TBGB.TAR	TRAWL	TB	0	sum/aut		
		WCSI.TAR	TRAWL	WCSI	0	sum/aut		
		TAR1	CPUE	FMA19	0	sum/aut		
		TAR2	CPUE	FMA2	0	sum/aut		
		TAR3	CPUE	FMA3	0	sum/aut		
TRE	Trevally	FMA8.TRE	TRAWL	FMA8	0	sum	Both	VL
		FMA9.TRE	TRAWL	FMA9	0	sum		
		TRE7	CPUE	FMA789	0	sum		
WAR	Common warehou	TBGB.WAR	TRAWL	TB	0	spr	Both	L
		WCSI.WAR	TRAWL	WCSI	0	spr		
WIT	Witch	TBGB.WIT	TRAWL	TB	0	all	Both	U
		WCSI.WIT	TRAWL	WCSI	0	all		
WWA	White warehou	SubA.WWA	TRAWL	SubA	0	spr	SI & SA	L

2.3 Analyses

The analyses essentially consisted of searching the data sets for significant correlations between fisheries and climate indices using two different statistical tests. The first test was a rank correlation over the whole time series. The second test was designed to determine only if the highest (or lowest) YCS or biomass index values occurred in the same years as the highest (or lowest) environmental or climate index values. The latter is therefore a test of whether the “extreme” values were aligned.

The results of the tests have been summarised, and also evaluated within a framework of several specific hypotheses:

- Climate effects should be most pronounced for short-lived species.
- Climate effect should be most pronounced in species which approach the limits of their range in New Zealand waters.
- Any substantial climate event should result in a response across multiple species.

Table 4: Summary of trawl surveys.

Survey label	Location	Timing (nominal month)	Depth range	No. of surveys (year range)	Main target species	Example reference
HG	Hauraki Gulf	Spring (Nov)	10–150 m	12 (1984–2000)	Snapper	Morrison et al. (2002)
BoP	Bay of Plenty	Spring (Nov)	10–300 m	6 (1983–1999)	Snapper	Morrison et al. (2001)
Chat	Chatham Rise	Summer (Jan)	200–800 m	15 (1992–2006)	Hoki	Stevens & O'Driscoll (2007)
TBGB	Tasman and Golden Bays	Late summer (Apr)	20–200 m	7 (1992–2005)	Giant stargazer, red cod, and others	Stevenson (2007)
WCSI	West coast South Island	Late summer (Apr)	20–400 m	7 (1992–2005)	Giant stargazer, red cod, and others	Stevenson (2007)
FMA8	West coast North Island	Spring (Nov)	10–200 m	4 (1989–1996)	Snapper	Morrison (1998)
FMA9	West coast North Island	Spring (Nov)	10–200 m	6 (1986–1996)	Snapper	Morrison (1998)
SubA	Subantarctic	Summer (Dec)	300–1000 m	9 (1991–2005)	Hoki, hake, and ling	O'Driscoll & Bagley (2008)

The only species identified as short-lived was arrow squid (Table 3). There were 15 species which were classified as southern, or with the centre of their biomass to the south. These were oblique banded rattail (CAS), banded rattail (CFA), dark ghost shark (GSH), pale ghost shark (GSP), hoki (HOK), southern blue whiting (SBW), white warehou (WWA), hake (HAK), blue cod (BCO), elephant fish (ELE), stargazer (STA), barracouta (BAR), red cod (RCO), spiny dogfish (SPD), and silver warehou (SWA). There were 11 species which were classified as northern. These were snapper (SNA), frostfish (FRO), rubyfish (RBY), leatherjacket (LEA), sand flounder (SFL), John dory (JDO), cucumberfish (CUC), northern spiny dogfish (NSD), trevally (TRE), grey mullet (GMU), and jack mackerel (JMN).

The evaluation focused on the larger and more reliable data sets, such as the research trawl surveys, and less on the short or intermittent time series or those with unidirectional trends (as discussed in Section 1.2).

In this study we did not determine the best specific predictors for each YCS or biomass series using the approach described by Francis et al. (2006) for two reasons. First, the model fitting with a cross-validation approach is useful for evaluating predictors and testing the performance of a model, but it is only sensible to apply this for a longer time series of data, and it is dependent on the appropriateness of the model (in Francis et al. (2006) this was a generalised linear model). Second, the development of a credible predictive model requires greater scrutiny of the data set than was possible for this study.

2.3.1 Data treatment and screening

The spatial and temporal resolution of data sources were highly variable. Some indices were available monthly, others were annual and used calendar years, and others (the majority) were annual but used fishing years (1 October to 30 September). For this analysis, all data were standardised to fishing years. Where data were labelled using a single year, this refers to the year ending, i.e., 2004 refers to the 2003–04 fishing year.

For YCS analyses, the monthly range of the environmental predictor within each year was restricted to a period reflecting the *Main Spawn Season*, as listed in Table 3. The year class strength (YCS) indices were also adjusted (offset) so that the year corresponded to the birth year, after assuming the spawning seasons given in Table 3. This required that the trawl surveys were allocated to a nominal month (Table 4).

For some trawl surveys, YCS was available for two adjacent age groups of the same species. These were not combined to obtain a single YCS. It should be noted, however, that the biomass estimates for the same cohort in subsequent years were not always highly correlated. This perhaps emphasises the uncertainty in some of the data (Figure 1).

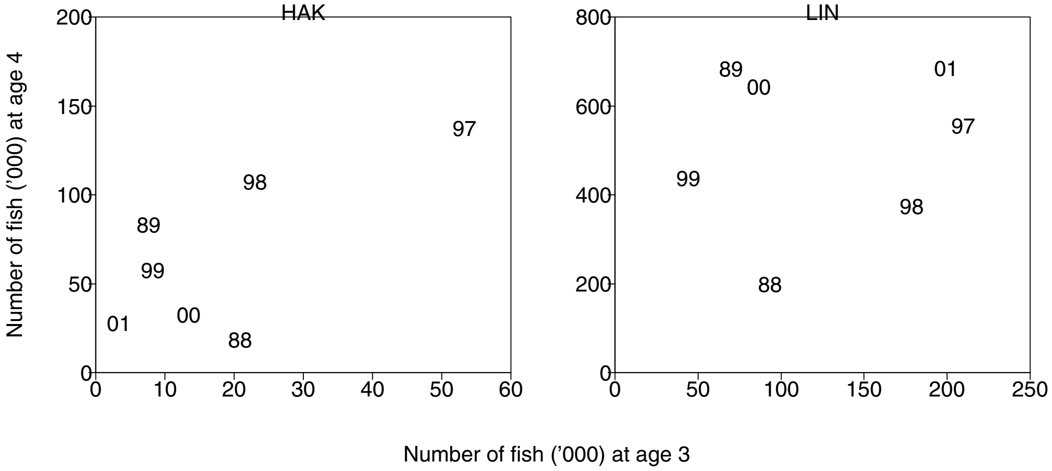

Figure 1: Comparison of pairs estimates of year-class biomass for HAK and LIN in trawl survey series SubA (the plotting symbol is the last two digits of the birth year of the year class).

There were also cases where the YCS for a species was highly correlated between two adjacent areas, notably for GUR and SWA between the WCSI and Tasman Bay (TB) (Table 5). These were treated as separate indices, and not combined into a single index.

Table 5: Correlations between YCS indices for the same species in different area.

First series	Second series	Correlation	Years in common
HAK1235689	HAK4	0.41	29
SKI1+9	SKI7+8	-0.02	16
GUR9	GUR1	-0.10	11
HAK1235689	HAK5+6	0.29	11
HAK4	HAK5+6	-0.32	11
BAR7WC	BAR7TB	0.28	10
RCO3-6	RCO7	-0.40	8
SNA1	SNA8+9	-0.39	8
GUR7WC	GUR7TB	0.83	7
SWA7WC	SWA7TB	0.92	7
RCO7WC	RCO7TB	0.19	7
HAK1235689	HAK7WC	-0.43	6
HAK4	HAK7WC	-0.16	6
GUR9	GUR9tr	0.54	5
GUR1	GUR9tr	-0.57	5

The first step in the analyses was predictor screening (Francis 2006), where environmental predictors were removed from the analysis set if they were unlikely to be related to the predictand, because of the area they were associated with. Predictor screening was subjective, and not based on the data or results. For example, the ZN index, of the strength of westerlies over the North Island, would not be expected to be related to YCS or biomass of species found in the subantarctic. The Trenberth and SOI predictors included for each area are shown in Table 6.

The chlorophyll indices were available only for YCS and biomass indices in the three areas, Chatham Rise, WCSI, and subantarctic. The SST and SSH were available as gridded files, therefore to select appropriate data for each series only the grid points which feed into defined polygons were used. These polygon areas were matched to the surveys or FMAs (Figure 2). The polygon used for each series is given in Table 4, and the areas shown in Figure 3.

Table 6: The area-specific environmental indices (predictors) and the Fisheries Management Area (FMA) and trawl survey area to which they were applied.

Environmental index	FMA	Survey Area
Z1 : Auckland -Christchurch	1,2,3,4,7,8,9	Chat, TB, WCSI
Z2 : Christchurch-Campbell	3,4,5,6,7	Chat, WCSI, SubA
Z3 : Auckland-Invercargill	1-9	Chat, TB, WCSI, SubA
Z4 : Raoul-Chatham	1,2,3,4,7,8,9	Chat, TB, WCSI
M1 : Hobart-Chatham	1,2,3,4,7,8,9	Chat, TB, WCSI
M2 : Hokitika-Chatham	2,3,4	Chat
M3 : Hobart-Hokitika	7,8,9	TB
MZ1 : Gisborne-Hokitika	3,4,7	Chat, WCSI, TB
MZ2 : Gisborne-Invercargill	3,5,6,7	WCSI,SubA
MZ3 : New Plymouth-Chatham	2,3,4,7,8	Chat,WCSI, TB
MZ4 : Auckland-New Plymouth	1,2,8,9	none
ZN : Auckland-Kelburn	1,2,8,9	TB
ZS : Kelburn-Invercargill	3,4,5,6,7	Chat, WCSI, TB, SubA

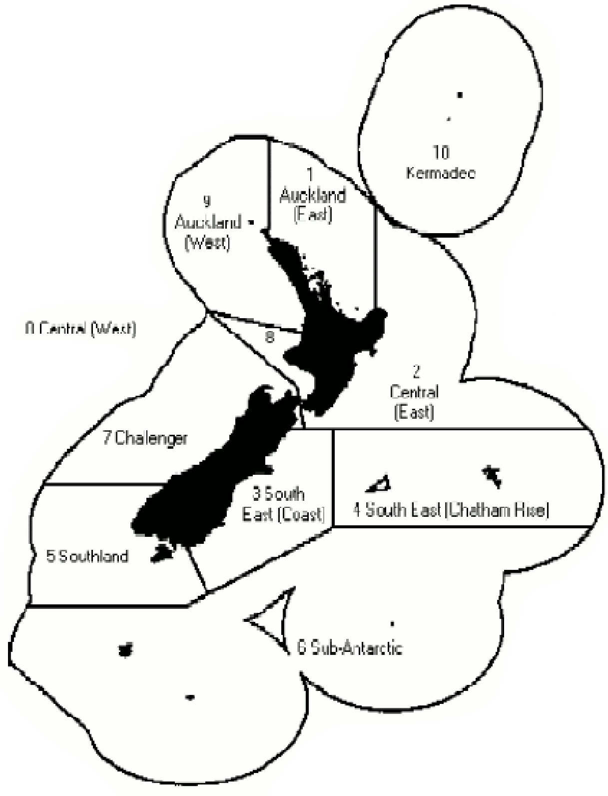

Figure 2: New Zealand Fisheries Management Areas (FMA) boundaries and labels. Reproduced from the MFish website (www.fish.govt.nz)

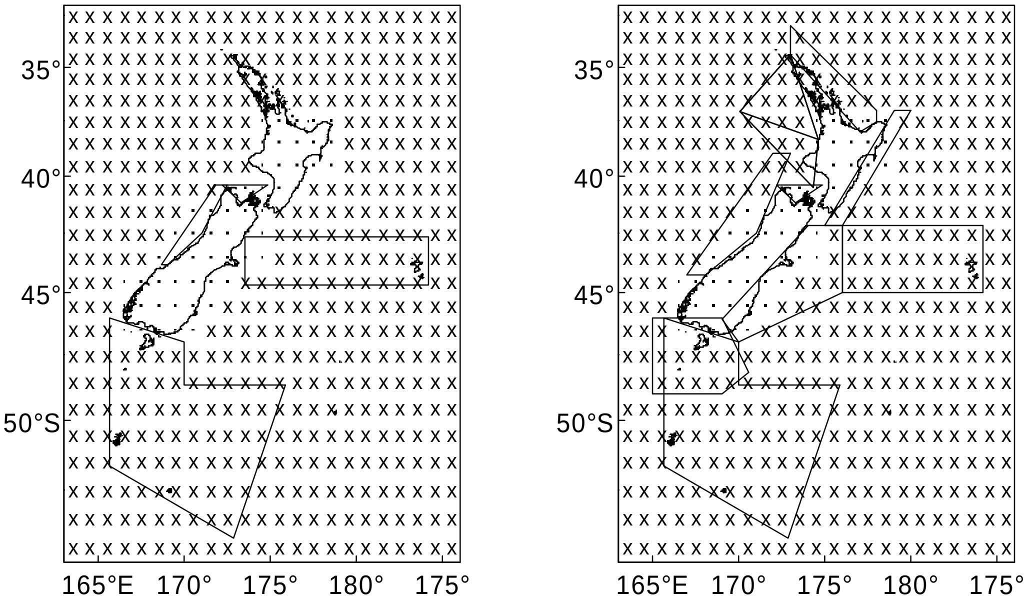

Figure 3: The SST (. and x) and SSH (x only) grid positions and data selection polygons. In the left panel, the polygons shown are, clockwise from bottom, SubA, WCSI, TB and CR. In the right panel, the polygons shown are, clockwise from bottom, FMA56, FMA5, FMA7WCSI, FMA7TB, FMA8, FMA9, FMA1, FMA2, FMA4, FMA3.

2.3.2 Statistical tests

In all statistical tests, the data (e.g., predictor and predictand) were restricted to the years that they had in common, and the test was not performed if this overlap was less than 5 years.

Two tests for association between the predictors and predictand were performed. First, the environmental predictors were tested for a significant correlation with the predictand. This used Spearman's rank correlation, as a 2-sided test (so the correlation could be either positive or negative). The test was assumed to be significant at the 5% level.

Second, a test of the association of the extremes of the predictor and predictand occurring together was performed. Each predictor and predictand was allocated into a bin: a low bin (L) for the values in the lower quantile, a high bin (H) for values in the upper quantile, and a medium bin (M) for the remainder. The probability that the H values occurred all in H-H pairs, or alternatively all in H-L pairs, was then tested. The null hypothesis was that the pairing of predictor and predictand occurred at random, and the probability calculated was the p-value for a test of this null hypothesis. Based on combinatorial arguments (Appendix C), the probability is:

$$\mathrm{p} = \frac{\binom{N-i-j}{N-m-n}\binom{m+n-i-j}{m-i}}{\binom{N}{m}\binom{N-m}{n}} \quad \text{where} \quad \binom{N}{k} = \frac{n!}{(n-k)!k!}$$

For example, in a series with 20 pairs of observations, 3 would be expected to be in the H bin and 3 in the L bin, leaving 14 in the M bin. If only 1 H-H pairing was in the H bin, and none in the low bin, the p-value would be 0.15 and not significant. If there were 2 H-H pairings in the H bin, and 1 L-L pairing in the L bin, the p-value would be 0.002, and significant. The test was assumed to be significant at the 5% level, and in this example, would mean at least 2 pairs (out of the possible 6) would have to be in the correct bins. For a shorter data series, for example with 7 pairs, the test would expect 1 H-H pair and 1 L-L pair, and both would have to be correctly associated for the p-value to be significant. The test was assumed to be significant at the 5% level. A significant result would therefore indicate that the extremes were paired together more often than would occur by chance. If the pairing was H-H, then the relationship was considered positive, if the pairing was H-L, the relationship was negative.

A final test used in the analyses was for time series (YCS or biomass) moving together. The null hypothesis for this test is that the series were unrelated, against the alternative that they were correlated with one another. The test calculated ranks for the observations in each series (r_{iy}: $i = 1,...,n_{\text{series}}$; $y = 1,...,n_{\text{year}}$), and then mean ranks across all series ($r_y = \text{mean}_i(r_{iy})$) (Table 7).

Table 7: An example of the allocation of YCS to ranks, and mean rank, for YCS indices from Tasman Bay.

		Year of birth						
	Series	1990	1992	1993	1995	1998	2001	2003
YCSs	SWA7TB	3.559	0.511	0.334	1.514	0.826	0.197	0.059
	GUR7TB	1.253	0.504	0.978	1.987	1.666	0.076	0.535
	RCO7TB	0.703	0.138	0.733	4.567	0.036	0.078	0.745
	TAR7TB	2.417	0.593	1.710	1.026	0.593	0.616	0.046
	BAR7TB	0.171	7.277	0.37	0.882	0.104	0.389	0.028
Ranks, r_{iy}	SWA7TB	7	4	3	6	5	2	1
	GUR7TB	5	2	4	7	6	1	3
	RCO7TB	4	3	5	7	1	2	6
	TAR7TB	7	2.5	6	5	2.5	4	1
	BAR7TB	3	7	4	6	2	5	1
Mean ranks, r_y		5.2	3.7	4.4	6.2	3.3	2.8	2.4

The closeness statistic, $s_{0,}$ indicates how closely the series are correlated with one another, and is estimated as:

$$s_0 = \left[\text{mean}_{i,y} \left(r_{iy} - r_y \right)^2 \right]^{0.5}$$

Low values of s_0 suggest that the series fluctuate synchronously. In order to see whether s_0 is small enough to reject the null hypothesis, the data were then replaced by random numbers (drawn from a uniform distribution), and the above calculation repeated to generate a new closeness statistic, s_1. This was done 1000 times, with 1000 different sets of random numbers, generating 1000 closeness statistics. The proportion of these randomly generated closeness statistics that were less than or equal to s_0 was taken as a p-value in our hypothesis test. The test was assumed to be significant at the 5% level. As an example, the test applied to the data in the example above returned an (only just) significant result of common years = 7; p-value = 0.048.

It is worth noting that when applied to a single pair of indices, this approach gives similar p-values to the Spearman rank correlation test. The Spearman rank correlation test was therefore used in pairwise analyses for simplicity.

3. RESULTS

3.1 Fisheries and climate correlations

The data set included 44 YCS and 168 biomass indices, and 253 significant rank correlations were found (Table 8). It is interesting to note that 79 additional significant rank correlations were excluded because the combination of predictor and predictand was screened (these are not shown in Table 8). The occurrence of 79 significant results for combinations highly unlikely to be true highlights the substantial potential for spurious correlations, and the importance of predictor screening.

Significant rank correlations were detected for 21 of the 48 YCS series (44%) and 86 of the 172 biomass series (50%). The significant rank correlations were most frequently with SST (N=43), SSH (N=28), Trough (N=26), Blocking (N=23) and SOI (N=22), followed by Z4 (N=16: Westerly winds over 30–45° S), M3 (N=13, Southerly winds over the Tasman Sea), and Zonal (N=13).

3.2 Short-lived species

The only species identified as having a short life span was arrow squid (see Table 3). On the WCSI, the assumed YCS had a significant negative correlation with SST, and a significant association with MZ4. However, this result is likely to be spurious, because the YCS index for the WCSI actually indexes an unknown mix of two different species, the southern species *Nototodarus sloanii* and northern species *N. gouldi*.

Uozomi (1998) found *N. gouldi* was the dominant species at the southern edge of the North Island, on the west coast of the South Island the species mix was about 50:50, and in the subantarctic the only species was *N. sloanii*. Because the separate species were not identified in trawl surveys, the species mix in the YCS and biomass indices (both derived from research trawl survey catch rates) was unclear, and could not be interpreted. But as low YCS was associated with high temperature we might hypothesise that the species being measured may have been predominantly the southern species, *N. sloanii*.

Table 8: Summary of the results of the rank correlation and association tests for each data series. The ‘series’ and ‘type’ describe the species, area, where relevant the age class, and the type of index (YCS, year class strength; TRAWl or CPUE, biomass; see Table 3). The ‘rank correlation’ and association test columns list the environmental or climate indices which were significant at the 5% level in the rank correlation or association tests. “–“ indicates no significant results.

Common name	Series	Type	Rank correlation	Association test
Arrow squid	TBGB.ASQ	TRAWL YCS	-	-
	WCSI.ASQ	TRAWL YCS	SST	-
	TBGB.ASQ	TRAWL	-	-
	WCSI.ASQ	TRAWL	Trough	-
Barracouta	BAR7TB	YCS (0+)	-	M1, M3, ZS, SOI, Trough, Zonal, Blocking, SST
	BAR7WC	YCS (1+)	-	M2, ZS, MZ1, Trough, Zonal
	BAR1.WCSI	YCS	-	-
	BAR2.WCSI	YCS	MZ1, Trough, Zonal	MZ1, Trough, Zonal
	BAR0.TB	YCS	Zonal	-
	BAR1.TB	YCS	-	-
	FMA8.BAR	TRAWL	-	-
	FMA9.BAR	TRAWL	-	-
	TBGB.BAR	TRAWL	-	-
	WCSI.BAR	TRAWL	-	-
	BAR1	CPUE	-	Z2, M3, ZS, MZ2, Trough, Zonal

Table 7 (cont.)

Common name	Series	Type	Rank correlation	Association test
	BAR5	CPUE	Trough	-
Banded bellowsfish	Chat.BBE	TRAWL	SSH	Z1, Z2, Z3, Z4, M1, M2, ZS, MZ1, SOI, Zonal, SSH
Blue cod	TBGB.BCO	TRAWL	-	-
	BCO5	CPUE	SOI, Trough, Blocking, SSH	SOI, Trough, Blocking, SST, SSH
Carpet shark	TBGB.CAR	TRAWL	Z1, Z4, ZN, MZ3, Trough, Blocking, SST	-
	WCSI.CAR	TRAWL	Z4, Blocking, SST	-
Oblique banded rattail	Chat.CAS	TRAWL	Z1, Trough, SSH	Z1, Z2, Z4, M1, M2, MZ1, SOI, Trough, Zonal, Blocking, SST, SSH
	SubA.CAS	TRAWL	-	ZS, MZ2, SOI
Two saddle rattail	Chat.CBI	TRAWL	M2, MZ3	Z1, Z2, Z4, M1, M2, ZS, MZ1, MZ3, SOI, Trough, Zonal, Blocking
Bollon’s rattail	Chat.CBO	TRAWL	Z3	Z2, Z3, Trough, Zonal, SST, SSH
Banded rattail	Chat.CFA	TRAWL	-	Z1, Z3, Z4, M1, M2, MZ3, SOI, Trough, Zonal, SSH
	SubA.CFA	TRAWL	Trough, Zonal, Blocking	Trough, Blocking, SST
Oliver’s rattail	Chat.COL	TRAWL	ZS	Z1, Z2, Z4, M2, MZ1, SOI, Zonal, Blocking, SST, SSH
	SubA.COL	TRAWL	Z2, mean, anom	Trough, mean, anom
Cucumber fish	WCSI.CUC	TRAWL	-	-
Elephantfish	WCSI.ELE	TRAWL	MZ1	-
	ELE3	CPUE	SOI, Blocking, SST, SSH	Z1, Z2, Z4, M1, M2, ZS, MZ1, MZ2, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
	ELE5	CPUE	-	Z3, ZS, MZ2, SOI, Blocking
Electric ray	TBGB.ERA	TRAWL	-	-
	WCSI.ERA	TRAWL	-	Z4, M1, ZS, MZ3, SOI, Trough, SST
N.Z. sole	TBGB.ESO	TRAWL	-	ZN
	WCSI.ESO	TRAWL	Z4, M1, M3, ZN, MZ3, SOI, Trough, Blocking, SST	Z4, M1, ZS, MZ3, SOI, Trough, SST
Deepsea flathead	Chat.FHD	TRAWL	-	Z2, ZS, MZ1, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
Frostfish	WCSI.FRO	TRAWL	Z4, M3, MZ3, Trough, Blocking, SST	M3, ZS, Blocking
Grey mullet	GMU1	CPUE	Z3	Z3, MZ4, Trough
Ghost shark	Chat.GSH	TRAWL	SST, SSH	Z1, M2, MZ1, MZ2, SOI, Zonal, SST, SSH
	SubA.GSH	TRAWL	-	Z4, SOI
	WCSI.GSH	TRAWL	Zonal	Z4, M1, ZS, MZ3, SOI, Trough, SST
Pale ghost shark	Chat.GSP	TRAWL	-	Z2, Z4, M1, M2, ZS, MZ1, MZ4, Zonal, mean, anom, SST, SSH
	SubA.GSP	TRAWL	Trough	Trough
Red gurnard	GUR1	YCS	-	Z1, Z3, M1, ZN, MZ3, MZ4, SOI, Trough, Blocking
	GUR7TB	YCS	M1	-
	GUR7WC	YCS	M1, M3, SOI	M1, MZ2, SOI, SST, SSH
	GUR9	YCS	-	Z3, MZ4, Trough, Zonal
	BoP.GUR	TRAWL	-	-
	FMA8.GUR	TRAWL	-	-

Table 7 (cont.)

Common name	Series	Type	Rank correlation	Association test
	FMA9.GUR	TRAWL	Z1, Z3, Z4, M1, ZN, SOI, Blocking, SST	Z1, Z4, M1, ZN, Blocking, SST
	HG.GUR	TRAWL	-	-
	TBGB.GUR	TRAWL	-	-
	WCSI.GUR	TRAWL	-	-
	GUR1	CPUE	-	M1
	GUR2	CPUE	Z4, MZ4, SOI, Trough, Zonal, SSH	Z1, Z4, M1, MZ3, SOI, Trough, Blocking, SST, SSH
	GUR3	CPUE	-	Z3, ZS, MZ2, Trough, Zonal
Hake	HAK1235689	YCS	-	Z2, Z3, MZ2, Zonal, Blocking, SST
	HAK4	YCS	SOI, Trough, Blocking, SSH	Z1, Z2, Z3, Z4, M1, M2, MZ1, MZ2, MZ3, SOI, Trough, Zonal, Blocking, SST
	HAK5+6	YCS	-	Z2, Zonal, mean, anom, SST
	HAK7WC	YCS	MZ3	-
	HAK3.SubA	YCS (3+)	Z2, Z3, MZ2, SST	Z2, Z3, Zonal, mean, anom
	HAK4.SubA	YCS (4+)	-	mean anom
	Chat.HAK3	YCS (3+)	Z2, Trough	Z1, Z2, Z3, Z4, M1, M2, Trough, Zonal, Blocking, mean, anom
	Chat.HAK4	YCS (4+)	Trough	Z1, Z2, Z3, Z4, M1, M2, ZS, MZ1, MZ3, SOI, Trough, Zonal, Blocking, SST
	Chat.HAK	TRAWL	SST, SSH	Z2, ZS, MZ1, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
	Chat.HAK3	TRAWL	SSH	Z1, Z3, SOI, Blocking, SST, SSH
	Chat.HAK4	TRAWL	-	Z1, Z3, M1, M2, ZS
	SubA.HAK	TRAWL	-	-
	SubA.HAKa	TRAWL	-	-
	WCSI.HAK	TRAWL	-	-
	HAK1	CPUE	M3, MZ4, Trough, Blocking, SST, SSH	Z1, Z4, M1, M3, ZN, ZS, MZ1, MZ3, MZ4, SOI, Trough, Blocking, SST, SSH
	HAK4cpue	CPUE	Trough, SSH	Z1, Z2, Z3, Z4, M1, ZS, MZ1, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
Hapuku	WCSI.HAP	TRAWL	Z4, M1, M3, Trough, Zonal, SST	Zonal
Hoki	HOKe	YCS (0)	-	Z1, Z2, Z3, Z4, M1, M2, ZS, MZ1, MZ3, SOI, Zonal, Blocking, SST, SSH
	HOKw	YCS (0)	SST	Z1, Z2, Z3, Z4, M1, M3, ZS, MZ1, MZ2, MZ3, SOI, Trough, Zonal, Blocking, SST
	HOK.chat	YCS (1+)	Z4, M1, SOI, Blocking, SST	Z1, Z2, Z3, Z4, M1, M2, ZS, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
	Chat.HOK	TRAWL	ZS, SST, SSH	Z2, Z3, M2, ZS, SOI, Blocking, SST, SSH
	SubA.HOK	TRAWL	-	Z3, ZS, MZ2, SOI
	WCSI.HOK	TRAWL	-	-
Javelinfish	Chat.JAV	TRAWL	SST, SSH	Z1, Z2, Z3, MZ1, SOI, Blocking, SST, SSH
	SubA.JAV	TRAWL	-	Trough
John dory	JDO9	YCS	-	-
	BoP.JDO	TRAWL	-	Z4, M1, M2
	BoP.JDO1	TRAWL	-	Z3

Table 7 (cont.)

Common name	Series	Type	Rank correlation	Association test
	FMA8.JDO	TRAWL	-	-
	FMA9.JDO	TRAWL	Zonal	-
	HG.JDO	TRAWL	-	Z3
	TBGB.JDO	TRAWL	-	-
	WCSI.JDO	TRAWL	MZ1	-
Jack mackerel (*declivis*)	TBGB.JMD	TRAWL	Zonal	Z4, M1, ZS, MZ3, SOI, Trough
	WCSI.JMD	TRAWL	Zonal	-
Jack mackerel (*murphyi*)	WCSI.JMM	TRAWL	Z4, Blocking, SST	-
Jack mackerel (*novaezelandiae*)	TBGB.JMN	TRAWL	Z3	Zonal
	WCSI.JMN	TRAWL	-	-
Lookdown dory	Chat.LDO	TRAWL	SOI, SST	Z1, Z2, Z4, ZS, MZ1, SOI, Blocking, SST, SSH
	SubA.LDO	TRAWL	ZS, SST	Blocking, SST
Leatherjacket	BoP.LEA	TRAWL	Trough	Z4, M1
	HG.LEA	TRAWL	-	Z1, Trough
	TBGB.LEA	TRAWL	Zonal	-
	WCSI.LEA	TRAWL	-	-
Ling	LIN5+6	YCS (3+)	Zonal	Z2, Z3, ZS, MZ2, Trough, SST
	LIN34	YCS (0)	-	Z1, Z2, Z3, Z4, M1, M2, ZS, MZ1, MZ2, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
	LIN56	YCS (0)	-	Z2, Z3, ZS, MZ2, SOI, Trough, Zonal, Blocking, SST, SSH
	LIN7WC	YCS (0)	M1, M3, SOI, SST, SSH	Z1, Z2, Z3, Z4, M1, M3, ZS, MZ1, MZ2, MZ3, SOI, Zonal, Blocking, SST, SSH
	LIN3.SubA	YCS (3+)	-	Z2, Zonal
	LIN4.SubA	YCS (4+)	-	-
	Chat.LIN3	YCS (3+)	-	Z1, Z3, M2, ZS, MZ1, MZ3, Trough, Zonal, mean, anom, SST
	Chat.LIN4	YCS (4+)	-	Z1, Z3, Z4, M1, M2, ZN, ZS, MZ1, MZ3, SOI, Zonal, SSH
	Chat.LIN	TRAWL	-	Z1, Z2, Z4, MZ3, Trough, Zonal, locking, SST, SSH
	Chat.LIN3	TRAWL	SST, SSH	Z1, Z2, Z4, M1, M2, MZ1, MZ3, SOI, Blocking, SST, SSH
	Chat.LIN4	TRAWL	SOI, SST, SSH	Z1, Z2, Z4, M1, M2, ZS, MZ1, MZ3, SOI, Trough, Zonal, Blocking, SST, SSH
	SubA.LIN	TRAWL	-	Trough
	WCSI.LIN	TRAWL	Z1	-
	LIN1	CPUE	M1, SOI, SST	Z3, M3, ZN, MZ4, SOI, Trough, Zonal, Blocking, SST
	LIN2	CPUE	SOI, Blocking, SSH	Z1, Z3, Z4, M1, M2, ZN, MZ3, MZ4, SOI, Trough, Zonal, Blocking
	LIN3&4	CPUE	SST, SSH	Z3, Z4, M1, ZS, MZ3, SOI, Trough, Blocking, SST, SSH
	LIN5&6	CPUE	-	Z3, ZS, MZ2, SOI, Trough, Blocking, SST, SSH
	LIN6	CPUE	-	Z2, Z3, ZS, Blocking, SST, SSH
	LIN7	CPUE	ZS, SST, SSH	Z2, Z3, ZS, MZ1, MZ2, SOI, SST, SSH
Lemon sole	TBGB.LSO	TRAWL	MZ1	-
	WCSI.LSO	TRAWL	Z4, Trough, Blocking, SST	-

Table 7 (cont.)

Common name	Series	Type	Rank correlation	Association test
Northern spiny dogfish	WCSI.NSD	TRAWL	-	-
Rubyfish	RBY2	CPUE	MZ4, Trough	-
Red cod	RCO3-6	YCS	-	Z1, Z2, Z3, MZ2, Trough, Zonal
	RCO7	YCS	-	Zonal
	RCO7TB	YCS	-	-
	RCO7WC	YCS	Blocking	SOI
	TBGB.RCO	TRAWL YCS	SST	SST
	WCSI.RCO	TRAWL YCS	SST	Trough
	RCO3	CPUE YCS	-	Z1, Z3, MZ2, SST, SSH
	RCO7cpue	CPUE YCS	Z1, Z3, ZS, MZ2	Z1, Z3, MZ2, MZ3, SST
	TBGB.RCO	TRAWL	-	-
	WCSI.RCO	TRAWL	Z1, Z4, Trough, Blocking, SST	Z1
	RCO3	CPUE	M2	M2, MZ1, MZ3, SSH
	RCO7	CPUE	-	Z2
Ribaldo	Chat.RIB	TRAWL	Z3, mean, anom	Z1, Z2, Z3, Z4, M1, ZS, MZ1, mean, anom, SST
	SubA.RIB	TRAWL	-	-
Rough skate	TBGB.RSK	TRAWL	Z4, M3, ZN, Trough, Blocking	M3, ZS, SST
	WCSI.RSK	TRAWL	MZ1	-
Southern blue whiting	SubA.SBW	TRAWL	-	SOI
	SBW6B	CPUE	Trough	ZS, Trough
	SBW6I	CPUE	SOI, SST	Z2, SOI, Trough, Zonal, Blocking
Scaly gurnard	TBGB.SCG	TRAWL	-	-
	WCSI.SCG	TRAWL	MZ1	-
School shark	FMA8.SCH	TRAWL	-	-
	FMA9.SCH	TRAWL	-	-
	TBGB.SCH	TRAWL	M1, MZ2, MZ3, SOI, SST	-
	WCSI.SCH	TRAWL	M3	-
	SCH1	CPUE	SOI, SST, SSH	Z1, Z3, Z4, M1, M3, SOI, SSH
	SCH3	CPUE	-	Z1, ZN, MZ1, MZ2, SOI, Trough, Zonal, SST, SSH
	SCH5	CPUE	-	Z2, Z3, ZS, MZ2, mean, anom, SST, SSH
	SCH7	CPUE	-	Z2, Z4, M1, M3, ZS, MZ2, MZ3, SOI, Trough, Zonal, SSH
	SCH8	CPUE	M3, Trough, Zonal	Z1, Z4, M1, M3, ZN, MZ3, MZ4, SOI, Trough, Zonal, Blocking, SST, SSH
Silver dory	Chat.SDO	TRAWL	-	Z2, Z3, M1, M2, ZS, MZ2, MZ3, Zonal, Blocking, SST
	WCSI.SDO	TRAWL	-	-
Sand flounder	HG.SFL	TRAWL	-	ZN, Zonal, Blocking
	TBGB.SFL	TRAWL	ZN	ZN
Gemfish	SKI1+9	YCS	-	Z1, Z3, M1, M3, ZN, MZ4, Trough, Zonal, Blocking, SST
	SKI7+8	YCS	Z4, SST	Z1, Z4, M1, M3, ZN, ZS, MZ1, MZ3, MZ4, Trough, Zonal, Blocking, SST
	WCSI.SKI	TRAWL	Z3, MZ2	-
	SKI1	CPUE	SSH	Z1, Z3, Z4, ZN, MZ4, SOI, Trough, Zonal, SST
	SKI2	CPUE	-	Z1, Z3, Z4, M1, M2, ZN, MZ2, MZ3, Trough, Zonal, Blocking

Table 7 (cont.)

Common name	Series	Type	Rank correlation	Association test
Snapper	SNA1	YCS	SOI, SST	Z3, Z4, M1, M2, ZN, MZ4, SOI, Trough, Blocking
	SNA8+9	YCS	-	Z4, MZ3, Zonal
	SNA9	YCS	-	Z1, ZN
	BoP.SNA	TRAWL	-	Z1,SOI, Blocking
	BoP.SNA2	TRAWL	-	-
	FMA8.SNA	TRAWL	-	-
	FMA9.SNA	TRAWL	-	-
	HG.SNA	TRAWL	Zonal, Blocking, SST	ZN
	SNA1cpue	CPUE	Z4, M1, SOI, Blocking, SST	Z1, Z3, Z4, M1, M2, ZN, MZ4, SOI, Blocking, SST
Shovelnose dogfish	Chat.SND	TRAWL	-	Z1, Z2, Z3, Z4, M1, M2, ZS, MZ1, SOI, Trough, Zonal, mean, anom, SST, SSH
Spiny dogfish	FMA8.SPD	TRAWL	-	-
	FMA9.SPD	TRAWL	-	-
	SubA.SPD	TRAWL	-	Z3, ZS, MZ1, MZ2, SOI
	TBGB.SPD	TRAWL	-	-
	WCSI.SPD	TRAWL	MZ1	Z2, MZ1, MZ2
	Chat.SPD	TRAWL	SOI, SST, SSH	Z2, Z3, Z4, M2, ZS, MZ1, SOI, Blocking, SST, SSH
	SPD3	CPUE	MZ3	Z1, M1, ZN, SSH
	SPD5	CPUE	-	Z3
	SPD6	CPUE	-	Z2, Zonal, SSH
	SPD7	CPUE	SSH	SOI, Zonal, SST, SSH
Sea perch	Chat.SPE	TRAWL	SST, SSH	Z2, Z3, M2, MZ1, Blocking, SSH
	TBGB.SPE	TRAWL	-	-
	WCSI.SPE	TRAWL	MZ1	-
	SPE3	CPUE	M2, SST	M2, MZ3
Rig	FMA8.SPO	TRAWL	-	-
	FMA9.SPO	TRAWL	-	SOI
	TBGB.SPO	TRAWL	-	-
	WCSI.SPO	TRAWL	-	-
	SPO3	CPUE	-	Z1, Z2, Z3, ZN, MZ3, Blocking
	SPO7	CPUE	-	Z1, Z2, ZN, MZ1, SST
	SPO8	CPUE	-	Z1, Z3, ZN, MZ4, SOI, SST, SSH
Smooth skate	WCSI.SSK	TRAWL	Z4, Trough, Blocking, SST	-
Stargazer	TBGB.STA	TRAWL	Z1	Z1
	WCSI.STA	TRAWL	-	-
	STA3	CPUE	Z1, Z3	Z1, Z2, Z3, Z4, M2, ZN, MZ1, MZ2, MZ3, SOI, Trough, Zonal, Blocking
	STA4	CPUE	-	-
	STA5	CPUE	-	Z3, ZS, MZ2, SOI, Zonal, mean, anom
	STA7	CPUE	M1, M3, SOI, Blocking, SST, SSH	Z1, Z4, M1, M3, ZS, MZ1, MZ2, MZ3, SOI, Trough, Blocking, SST, SSH
Silver warehou	SWA7TB	YCS	-	-
	SWA7WC	YCS	M2	-
	TBGB.SWA	TRAWL	-	Zonal
	WCSI.SWA	TRAWL	Z3, MZ1, MZ2	Z2, MZ1, MZ2
Tarakihi	TAR7TB	YCS	-	-
	TBGB.TAR	TRAWL	M3	-
	WCSI.TAR	TRAWL	-	-

Table 7 (cont.)

Common name	Series	Type	Rank correlation	Association test
	TAR1	CPUE	-	MZ4, SSH
	TAR2	CPUE	SOI, SST, SSH	Z1, Z4, ZN, SOI, Blocking, SST
	TAR3	CPUE	-	Z1, Z4, M1, M2, ZN, ZS, MZ3, SOI, Trough, Blocking, SST, SSH
Trevally	FMA8.TRE	TRAWL	-	-
	FMA9.TRE	TRAWL	-	-
	TRE7	CPUE	MZ4, Trough	Z1, Z2, Z3, Z4, M1, M3, ZN, ZS, MZ2, MZ3, MZ4, SOI, Trough, Zonal, Blocking, SST, SSH
Common warehou	TBGB.WAR	TRAWL	-	-
	WCSI.WAR	TRAWL	Z1, Z3	Z3
Witch	TBGB.WIT	TRAWL	Z4, M3, ZN, Trough, Blocking	M3, ZS, Blocking, SST
	WCSI.WIT	TRAWL	-	-
White warehou	SubA.WWA	TRAWL	Z3, MZ2	-

3.3 Cold water species

3.3.1 Common trends in YCS and biomass of cold water species

There was no significant common trend in YCS indices when adjusted to the birth year, for the following species datasets: WCSI (HOKw & species with -1 year offset, N=3, common years=5, p=0.61; HOKw & species with -2 year offset, N=5, common years=7, p=0.15), or the Chatham Rise (HAK4 & HOKw, N=2, common years=26, p=0.53; Chat.HAK3 & HOK.Chat, N=2, common years=13, p=0.09). The only YCS indices available for the subantarctic were for hake.

The biomass indices from the Chatham Rise trawl survey did not show any common trend (N=7, common years=15, p=0.61). Combined with the YCS result, this suggests no common catchability or YCS influence amongst these species on the Chatham Rise.

The biomass indices from the WCSI trawl survey showed a significant common trend (N=9, common years=6, p=0.003), with all of the indices except dark ghost shark and silver warehou showing an overall decline between the first half on the index and the second half. When examined in finer detail, however, common patterns were not obvious, except for a similar pattern in red cod and spiny dogfish. For red cod, spiny dogfish, and stargazer biomass indices were also available from WCSI fisheries, but these did not show a common trend (N=3, common years=9, p=0.26). This suggests there may be a common catchability effect amongst cold water species in the WCSI trawl survey.

The biomass indices from the subantarctic showed a significant common pattern for the trawl survey (N=10, common years=9, p<0.001), but not for the commercial CPUE indices (N=4, common years= 8, p=0.91). Detailed examination suggested similar biomass patterns in the subantarctic trawl survey between banded rattail, hake, dark ghost shark and pale ghost shark (N=4, common years=9, p<0.001), hoki and oblique banded rattail (N=2, common years=9, p=0.02), and white warehou and spiny dogfish (N=2, common years=9, p=0.04).

3.3.2 Relationships with climate for cold water species

Six of the 12 cold water species showed correlations with climate indices that could be consistent with increasing recruitment and catchability towards the northern limit of their range when temperatures were lower and southerly winds stronger (Figure 4).

Banded rattail biomass on the Chatham Rise had a negative correlation with SSH. Hake YCS on the Chatham Rise, estimated from the stock assessment model, had a negative correlation with SOI and Blocking, and hake biomass a negative correlation with SST and SSH, although the trend was unidirectional. However, the index of 3+ hake from the Chatham Rise trawl survey suggests a recovery in YCS in 2005–06, which correlated with SSH and Trough. Hake YCS in the subantarctic had a weak negative correlation with SSH, but was unclear as the subantarctic time series was short. Barracouta biomass on the WCSI had no correlation with SST or SSH, but a significant positive correlation with the Trough regime suggested catchability was higher in cooler conditions. Hoki YCS from the Chatham Rise trawl survey had a weak negative correlation with SST, Blocking, and SOI, and a weak positive correlation with stronger southerlies and westerlies (M1 and Z4), but the model output YCS had no significant correlation. The negative correlation between hoki biomass and SSH appeared stronger but reflected predominantly one-way trends, with a major fish-down of hoki having taken place during the late 1980s and 1990s. Red cod biomass on the WCSI had a significant positive correlation with the Trough regime, and negative with SST, suggesting catchability was higher in cooler conditions. Silver warehou biomass on the WCSI had a negative correlation with MZ1 and MZ2, implying lower catchability with strong northwesterlies.

Six of the 12 southern species showed correlations with climate indices that could be considered inconsistent with increasing recruitment and catchability towards the northern limit of their range when temperatures were lower and southerly winds stronger (Figure 4).

Blue cod biomass off Southland had a positive correlation with SSH, SOI, and the Blocking regime, and a negative correlation with Trough, although the biomass trend was unidirectional (it increased). Oblique-banded rattail biomass on the Chatham Rise was positively correlated with SSH, and weakly negatively correlated with Trough, but the biomass index was increasing roughly 1 year ahead of the SSH, which suggests no causal link. Elephantfish biomass on the east coast of the South Island had a strong positive correlation with SST and SSH. Elephant fish biomass off Southland (ELE5) had a similar trend, but there were no significant correlations with climate. Dark ghost shark biomass on the Chatham Rise had a weak positive correlation with SST and SSH, but these were predominantly unidirectional. Stargazer biomass on the WCSI from CPUE (STA7) had a positive correlation with SST and SOI, whereas stargazer biomass (CPUE) off Southland had no clear association with SOI. There was also no significant correlation for stargazer in the WCSI trawl survey (WCSI.STA), which was also inconsistent with the fishery index. Spiny dogfish biomass on the Chatham Rise had a significant positive correlation with SST, SSH and SOI. Southern blue whiting is a predominantly southern subantarctic species, and the eastern stock (SBW6B) appeared positively correlated with Trough, with an notable outlier in 1994. White warehou correlations were unclear.

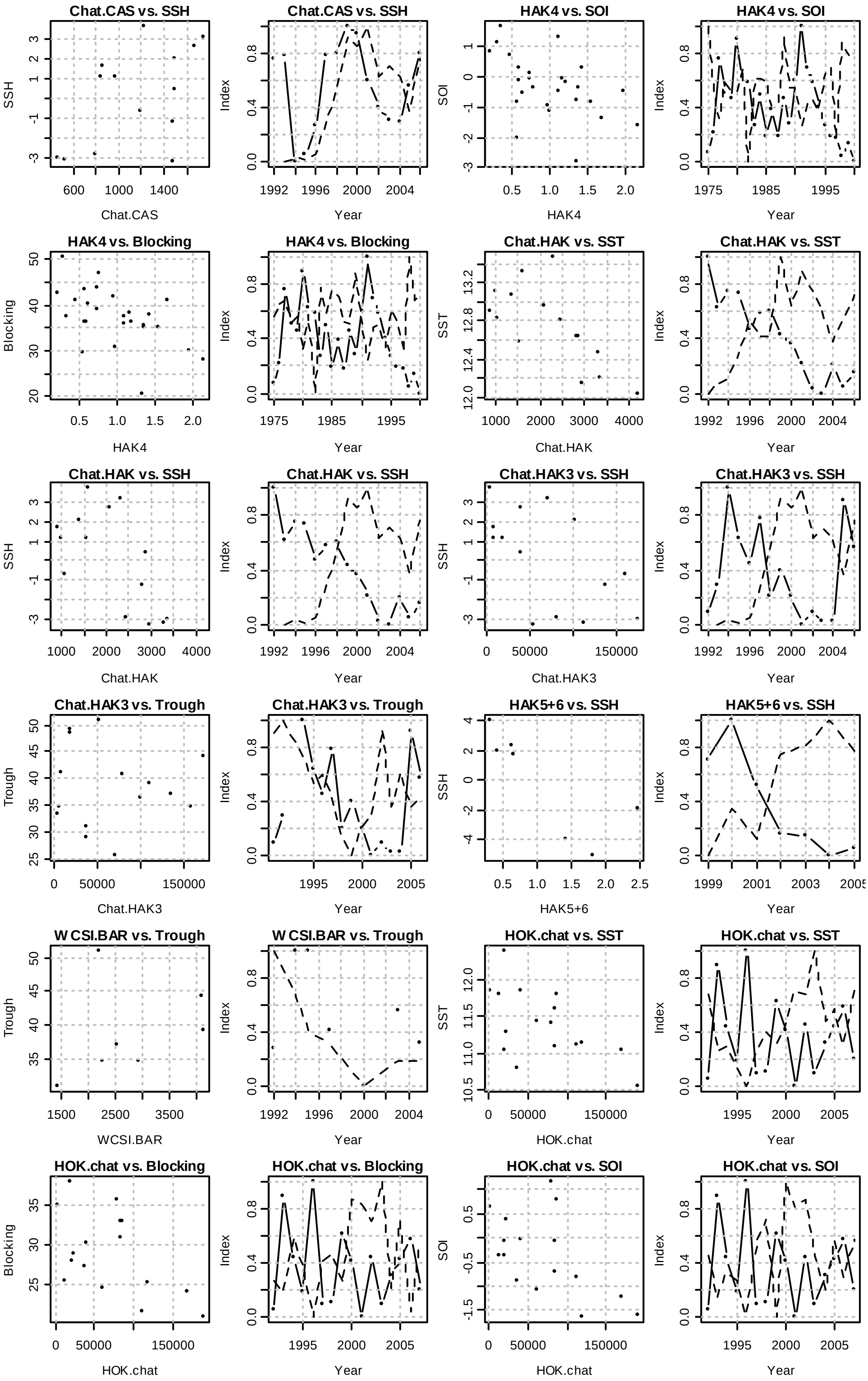

Figure 4: Relationships between fisheries and climate indices for cold water species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

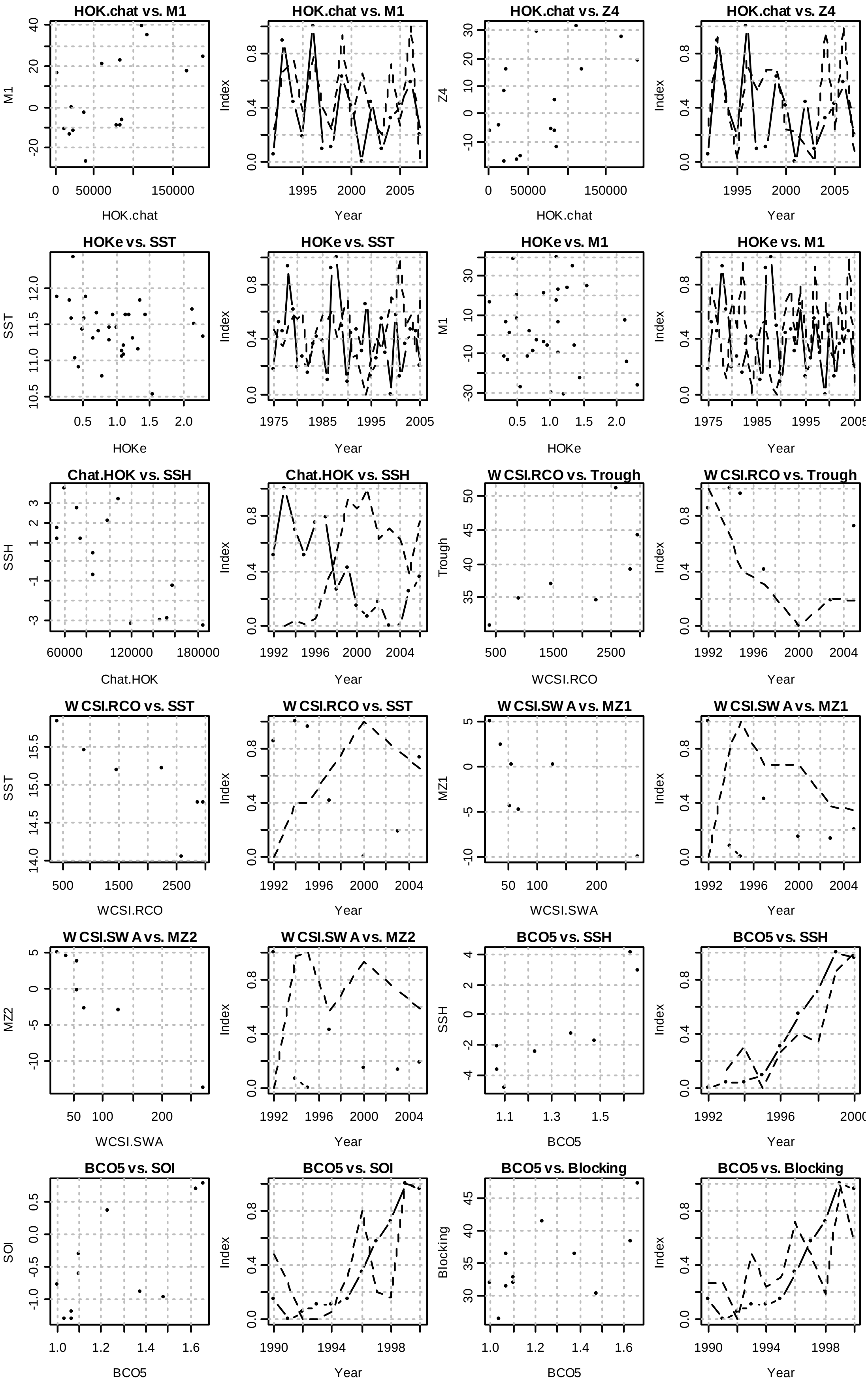

Figure 4 (cont.): Relationships between fisheries and climate indices for cold water species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

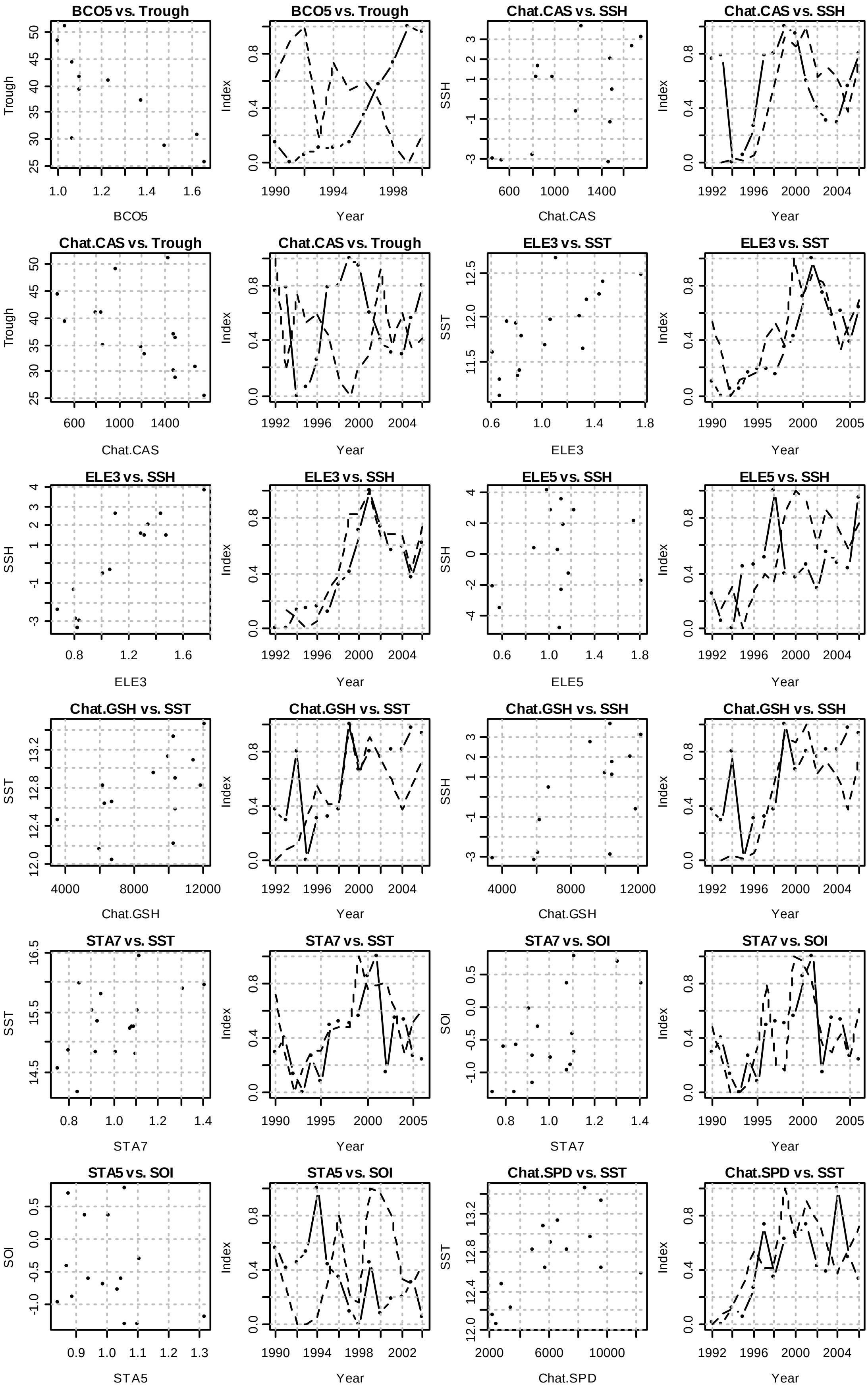

Figure 4 (cont.): Relationships between fisheries and climate indices for cold water species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

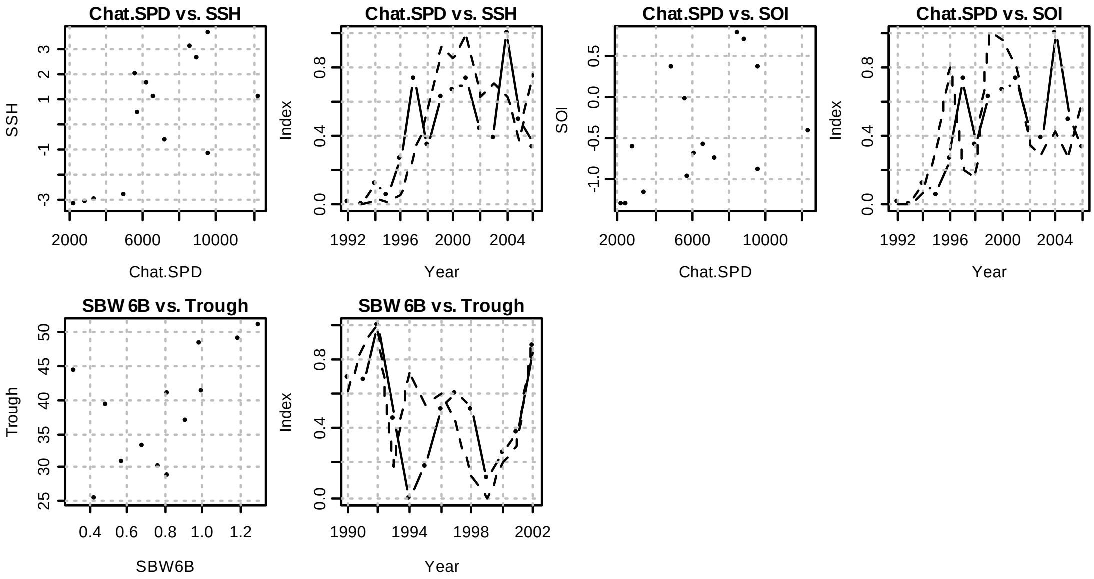

Figure 4 (cont.): Relationships between fisheries and climate indices for cold water species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

3.4 Warm water species

3.4.1 Common trends in YCS and biomass for warm water species

YCS indices were available only for snapper, and so no comparisons with other species could be made. Overall, there was no significant common trend in biomass indices for the WCSI (N=8, common years=6, p=0.74), and only limited comparisons could be made around the North Island because of the lack of common years, but where they could be compared these also had no common trends (N=4, common years=5, p=0.75). This suggests no common catchability influence amongst the warm water species.

3.4.2 Relationships with climate for warm water species

Two of the 11 northern species (snapper and frostfish) showed correlations with climate indices that could be consistent with increasing recruitment and catchability towards the southern limit of their range when temperatures were higher and northerly winds stronger (Figure 5).

For snapper in the East Northland, Hauraki Gulf, and Bay of Plenty stock (SNA1), the positive correlation between YCS and SST has been previously reported, and was found here (it is the same data set) along with a positive correlation with SOI. No similar correlations were found for any other snapper stock. The plot of YCS for SNA 1 and SOI suggests a possibly non-linear (asymptotic) relationship. Snapper biomass for SNA 1 also had a positive correlation with SST, although this was weak. Frostfish biomass on the WCSI was negatively correlated with increased southerlies (M3), and positively correlated with Blocking; this is consistent with higher catchability with decreased southerlies and increased temperature. Indices were not available for frostfish from any other areas.

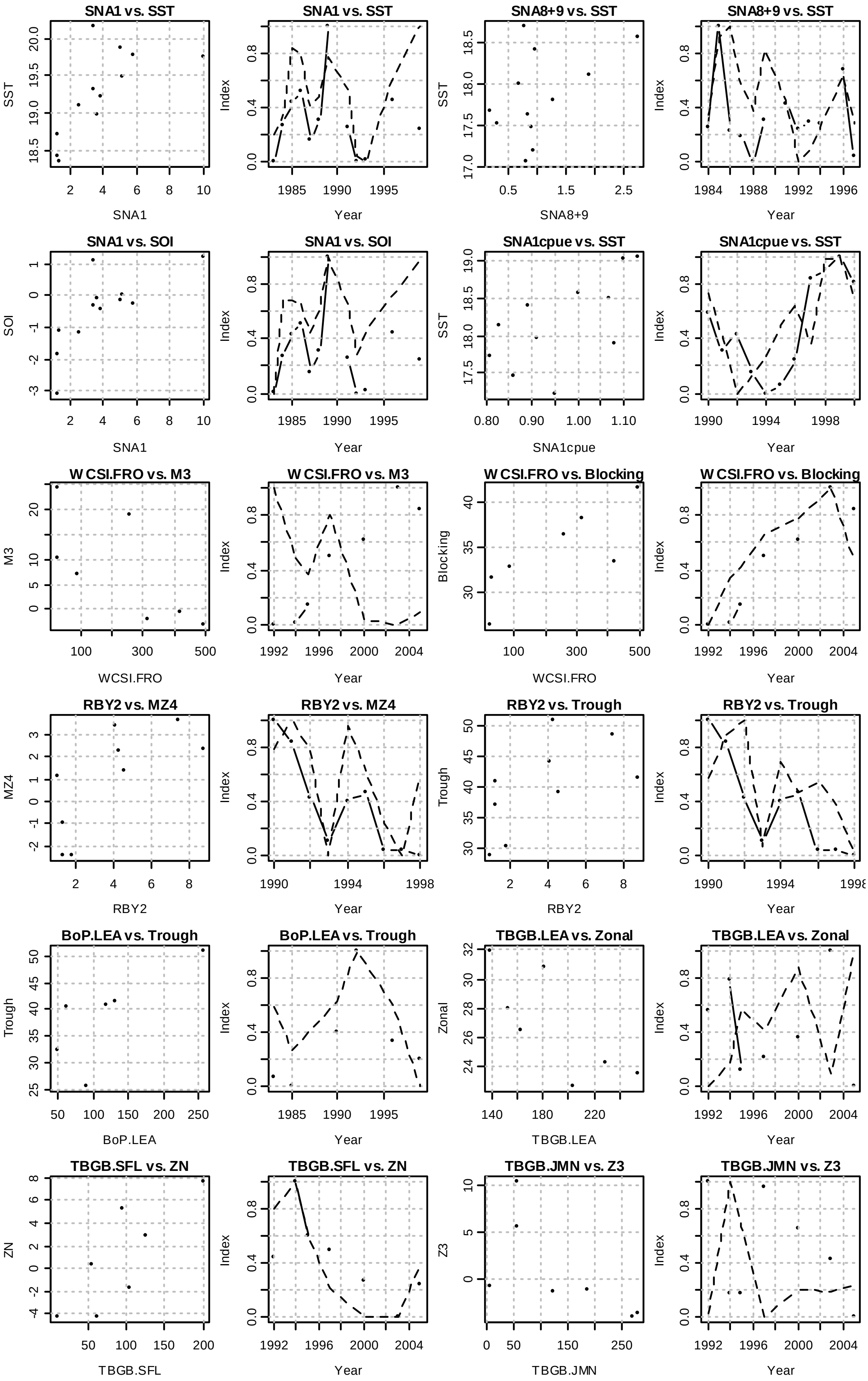
SNA1 vs. SST
SNA1 vs. SST
SNA8+9 vs. SST
SNA8+9 vs. SST
SNA1 vs. SOI
SNA1 vs. SOI
SNA1cpue vs. SST
SNA1cpue vs. SST
W CSI.FRO vs. M3
W CSI.FRO vs. M3
W CSI.FRO vs. Blocking
W CSI.FRO vs. Blocking
RBY2 vs. MZ4
RBY2 vs. MZ4
RBY2 vs. Trough
RBY2 vs. Trough
BoP.LEA vs. Trough
BoP.LEA vs. Trough
TBGB.LEA vs. Zonal
TBGB.LEA vs. Zonal
TBGB.SFL vs. ZN
TBGB.SFL vs. ZN
TBGB.JMN vs. Z3
TBGB.JMN vs. Z3

Figure 5: Relationships between fisheries and climate indices for warm water species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

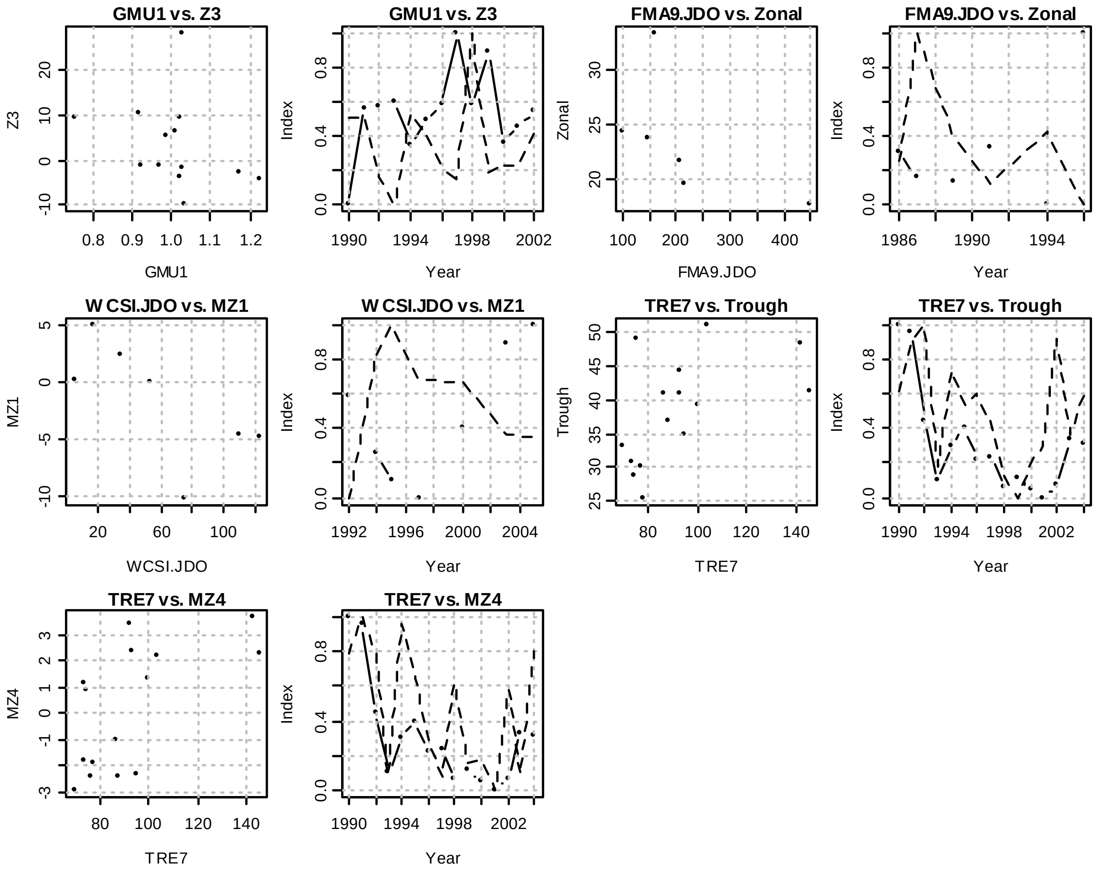

Figure 5 (cont.): Relationships between fisheries and climate indices for warm water species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

Two of the 11 northern species (rubyfish and leatherjacket) showed correlations with climate indices that could be considered inconsistent with increasing recruitment and catchability towards the southern limit of their range when temperatures were higher and northerly winds stronger. Rubyfish biomass on the east coast North Island was positively correlated with MZ4 and Trough, and both relationships looked rather non-linear; higher values of MZ4 and Trough indicate stronger westerlies and cooler conditions. Leatherjacket biomass in the Bay of Plenty was weakly positively correlated with Trough, and negatively correlated with Zonal in Tasman and Golden Bays, both consistent with higher catchability in colder years.

The results were unclear for the remaining seven species. Sand flounder biomass in Tasman and Golden Bays had a positive correlation with ZN, indicating higher biomass with stronger westerlies. Jack mackerel (JMN) biomass in TBGB was also negatively correlated with strong westerlies (Z3). Grey mullet biomass around the North Island was weakly negatively correlated with westerlies (Z3). John dory biomass on the west coast of the North Island (FMA9) had a weak negative correlation with Zonal, and in WCSI a weak negative correlation with MZ; the lack of any clear correlations for John dory is surprising given that an increase in SST had been implicated in increased catch rates in recent years. Trevally biomass on the WCSI (TRE7) had a positive correlation with Trough and MZ4, with no clear interpretation. Northern spiny dogfish biomass had no significant correlations with climate. Cucumber fish biomass had no significant correlations with climate.

3.5 The Chatham Rise

There are several species which seemed to have similar trends in biomass on the Chatham Rise (Figure 6). The first group of species showed a general increase in biomass over the mid to late 1990s, with biomass then remaining relatively high, and included banded bellowsfish, dark ghost shark, javelinfish, Oliver's rattail, sea perch, lookdown dory, spiny dogfish, and flathead (N=8, common years=15, p<0.001). Ling, oblique banded rattail and Bollons's rattail showed a second and more cyclical pattern, with a decrease in biomass in the early 1990s, followed by an increase in the late 1990s (similar to the first group), and then a decrease, (N=3, common years=15, p=0.01). All of the above trends relate to biomass and have significant correlations (to various extents) with temperature (SST, SSH), as this increased between the early 1990s and around 2000.

This suggests a common catchability effect across these species, with higher catchability correlated with higher SST. Three of these species were classified as cold-water species (oblique-banded rattail, dark ghost shark, and spiny dogfish), and had significant relationships with climate that were the reverse of what was expected (i.e., higher biomass correlated with warmer years, see Section 3.3). Because these cold-water species have trends similar to the "other" species in this section, this suggests that either the common biomass patterns may be spurious, the correlations with SST/SSH may be spurious, or the hypotheses behind the earlier analysis of cold and warm-water species were incorrect (i.e., the species chosen were indeed 'cold-water' species, the other species weren't cold-water species, and species on the edge of their range should show similar responses to changes in environment or climate).

Other species from the Chatham, including hoki, hake, two-saddle rattail, banded rattail, pale ghost shark, ribaldo, silver dory, shovelnose dogfish and stargazer Rise, showed no consistent pattern in biomass trend. There was no consistent trend amongst the YCS indices. Three of these species were classified as cold-water (hoki, hake, and banded rattail), and had significant correlations with climate which were as expected (i.e., higher biomass correlated with cooler years, see Section 3.3). It is again possible that these relationships were spurious, but it could be that these three species were influenced by environmental or climatic conditions in a different way (i.e., through a different mechanism) to oblique-banded rattail, dark ghost shark, and spiny dogfish.

3.6 West Coast South Island

There were more biomass indices available for the WCSI (including TBGB) than for any other region, and several species showed similar trends in biomass which were significantly correlated with climate indices. The TBGB indices haven't been analysed in any great detail, as there were few trawl stations, and the coefficients of variation for the biomass estimates were high. The WCSI trawl survey series was short, and thereby susceptible to spurious correlations. As a result, even though some common trends were evident, any correlation with climate indices remains especially speculative.

Species which showed a decline in biomass in the WCSI research trawl survey were rough skate, smooth skate, carpet shark, NZ sole and elephantfish (N=5, common years=7, p=0.001; Figure 7). Because all of these indices showed a decline, any environmental series that showed a decline or inversely an increase over the same period produced a significant correlation (e.g., SST, Blocking, MZ1, Trough). The biomass of ling from CPUE showed a similar declining trend. The biomass of frostfish and hapuku increased over the same period (N=2, common years=7, p=0.02), and similarly had correlations with the same set of environmental indices.

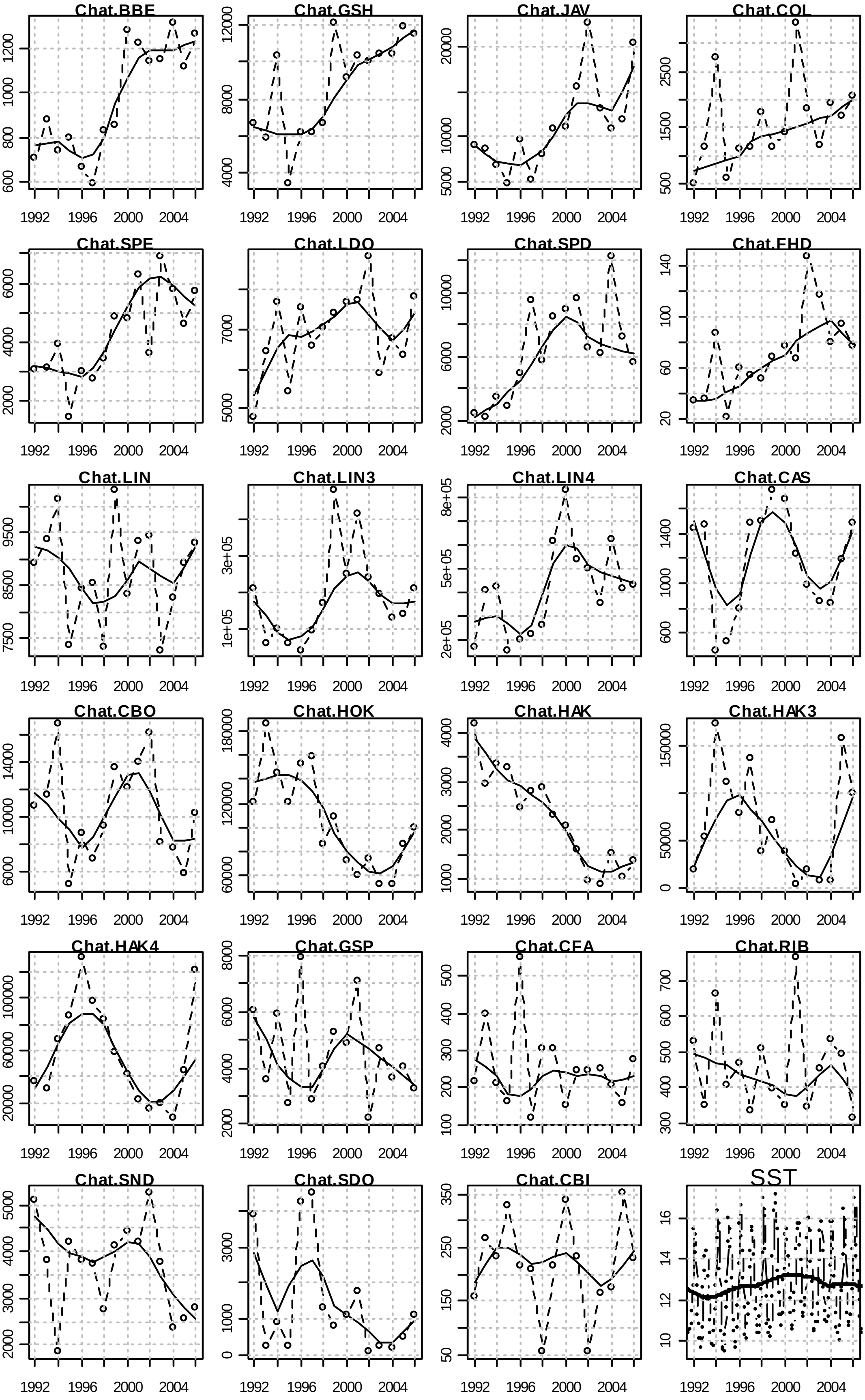

Figure 6: Biomass indices from the Chatham Rise trawl survey (points and broken lines), with a loess smoother line added (solid line) to emphasise the overall trend (all panels except bottom right). The bottom right panel shows an index of sea surface temperature (SST) for the Chatham Rise over the same period by month (points and broken line) and with a loess smoother (solid line).

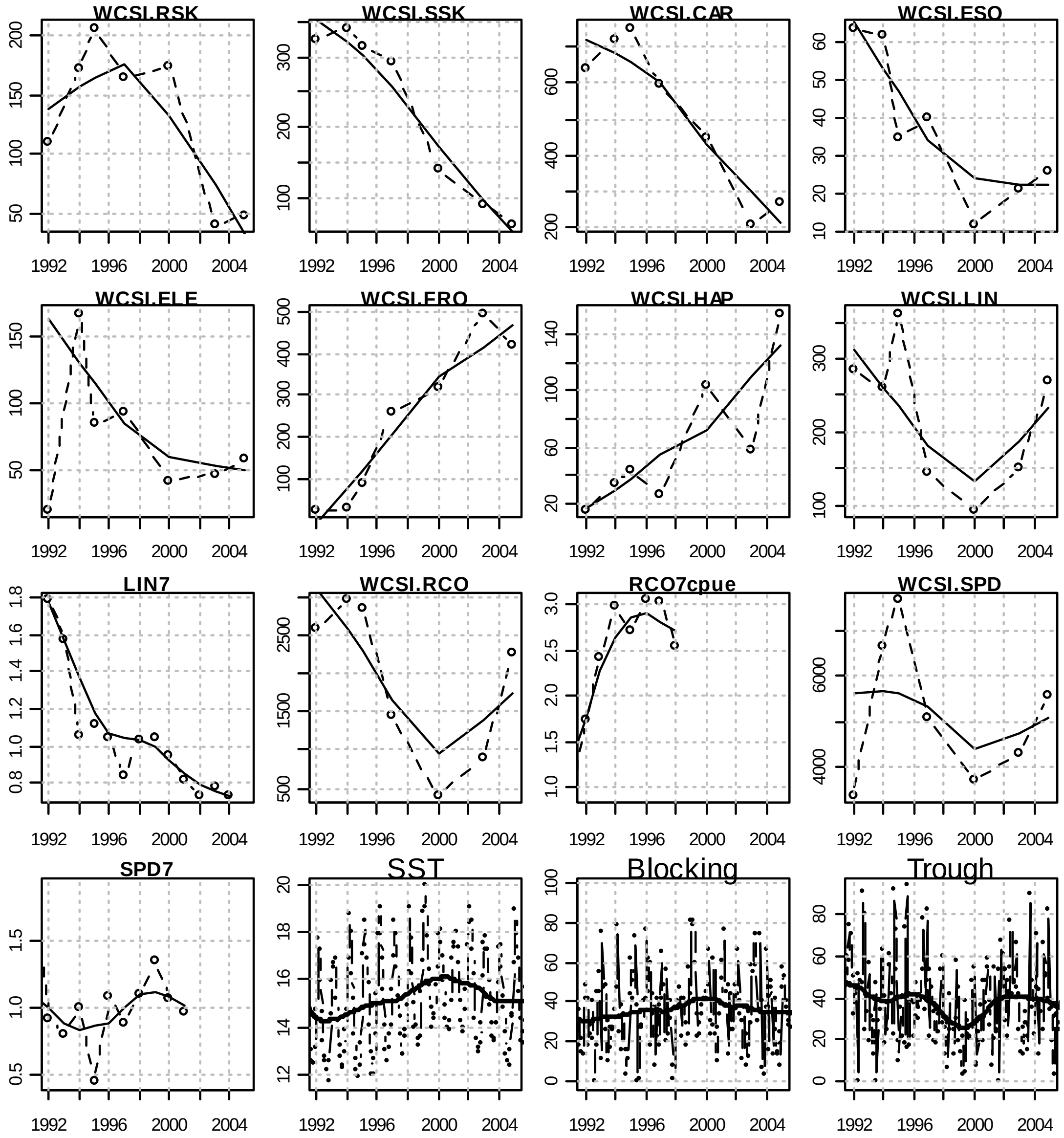

Figure 7: Biomass indices from the West Coast South Island (points and broken lines), with a loess smoother line added (solid line) to emphasise the overall trend (all panels except bottom right). Those from the research trawl survey are prefixed 'WCSI'. The last 3 panels in the bottom show indices of sea surface temperature (SST), and the Blocking and Trough Kidson regimes, for the same area over the same period by month (points and broken line) and with a loess smoother (solid line).

Red cod and spiny dogfish indices decreased and then increased over the same period (N=2, common years=7, p=0.009), and were positively correlated with increased westerlies (M1) or northwesterlies (MZ1) (Figure 7). However, these indices had different trends from the commercial (CPUE) indices for the same stock (Figure 7). The rest of the YCS and biomass indices showed no obvious common trend.

3.7 Rank correlation and association tests

The association test was developed because we hypothesised that the extreme events in climate indices might have a correlated effect on YCS or biomass, but the smaller year-to-year smaller fluctuations might not. Unlike the rank correlation test, the association test used only the upper and lower quantiles of the data, thereby ignoring the fluctuations around the median. Cases where only extreme anomalies have a clear impact might be expected in stocks found towards the middle of a species' range, where environmental conditions are less challenging, and therefore climate impacts might only be visible when an environmental-biological threshold is occasionally reached or exceeded.

In general, when a climate-YCS or biomass relationship was significant for the rank correlation test, it was also significant for the association test. There were cases, however, where the association test was significant but the rank correlation test was not, and a few instances when the reverse was true. For example, the hoki YCS index for the east coast (HOKe) was significant for the association test but not the rank correlation test. There was a weak negative correlation with SST (non-significant, Figure 8). The association test was significant because relatively low YCS were associated with relatively high SST, but at lower SST the YCS were not associated.

For gemfish (SKI1+9), there was a period of relatively high YCS with relatively low frequency of the Trough regime, then a peak and relatively high frequency of the Trough regime associated with relatively low YCS (Figure 8).

There were a few cases where a significant result was returned from the rank correlation but not the association test. These seem to be where the data series was relatively short, i.e., less than 10 years (e.g., HAK4.SubA, SKI1). In these cases, if only one or two of the extreme pairs were not correctly associated then a non-significant result was returned.

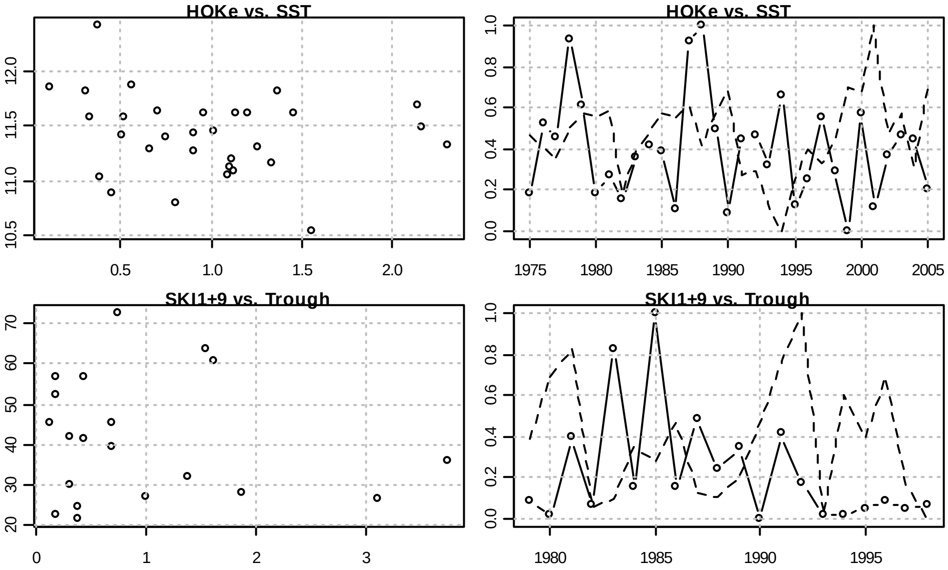

Figure 8: Indices for hoki recruitment on the Chatham Rise (HOKe) and sea surface temperature (SST), and gemfish around the northern North Island (SKI1+9) and the Kidson Trough regime. The left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1)

3.8 Notable results

There were several cases where the results indicated a likely climate effect. These were more often with biomass (i.e., catchability) than YCS. These cases would be worthy of further detailed study, to assess their validity and nature.

For example, the correlation between school shark biomass on the west coast North Island (SCH8) and the Trough regime could be caused by spatial movement of the fish (as suggested by opposing biomass trends in adjacent areas, Ayers et al. (2006)), or it could be because stronger westerly winds make the fishing gear less efficient, or restrict the fishers in the areas they can work, thereby modifying catchability. Determining which of these is more likely would require more detailed study of the fisheries and the available biological data. The biomass trend for SCH1 has some features in common with SCH8 (although the common trend is not significant; p=0.09), SCH7 and SCH5 have a common mode around 1998–1999, and SCH7 ad SCH8 appear to be inversely correlated (Figure 9).

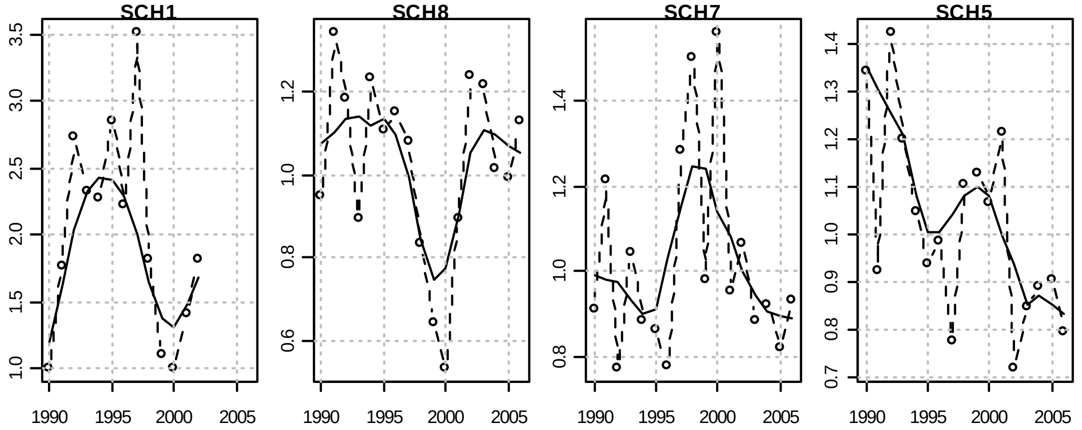

Figure 9: School shark biomass indices (points and broken lines) by FMA, with a loess smoother line added (solid line) to emphasize the overall trend

Commercial species abundance series where there are relatively clear, and significant, correlations between fisheries and climate indices, and so could be worthy of further investigation include:

- Elephantfish (e.g., ELE3 vs SST, SSH; Figure 4)
- School shark (e.g., SCH8 vs Trough, Zonal; SCH1 vs SOI, SST; Figure 10)
- Red gurnard (e.g., GUR2 vs Trough, GUR7WC vs M1, SOI, FMA9GUR vs SOI, SST; Figure 10)
- Stargazer (e.g., STA7 vs SST, SOI, Blocking; Figure 4)
- Hake (e.g., HAK4 vs Trough, Chat.HAK3 vs SSH; Figure 4)
- Tarakihi (e.g., TAR2 vs SST; Figure 10)

The time series of trawl surveys with similar cycles across species may also warrant further investigation:

- Chatham Rise: Oblique banded rattail, Bollons's rattail, and ling (Figure 6)
- Subantarctic: Banded rattail, Oliver's rattail, pale ghost shark, dark ghost shark, and southern blue whiting (Figure 11).

The relationship between snapper YCS and SST previously described was found for SNA 1 (Francis 1994a), but with a possible catchability and SST relationship.

The results for hoki YCS from the model were unclear and therefore agreed with Francis et al. (2006). The hoki 1+ YCS estimates from the Chatham Rise survey (i.e., not the assessment model) showed some correlation with a variety of local climate variables, the strongest being M1, and therefore agreed with earlier observations by Bull & Livingston (2001) (see Table 5). The significant correlation between hoki 1+ YCS and SST is negative; there was a similar significant negative correlation between total hoki biomass (Chat.HOK) and SST. It is therefore conceivable that climate may play a part either in the first appearance of cohorts into the Chatham Rise bottom trawl fishery, or in the overall biomass of hoki available to the trawl survey. The hoki on the Chatham Rise are believed to originate from spawnings in Cook Canyon (southeast corner of the North Island), or the west coast of the South Island, but the relative proportions recruiting from each area are unknown (Ministry of Fisheries Science Group 2007). Using SST from other areas (e.g., west coast South Island) would produce the same result as using SST from the Chatham Rise, as SST for the west coast South Island, east coast South Island, and Chatham Rise are highly correlated (coefficient values 0.88–0.9, Table 1).

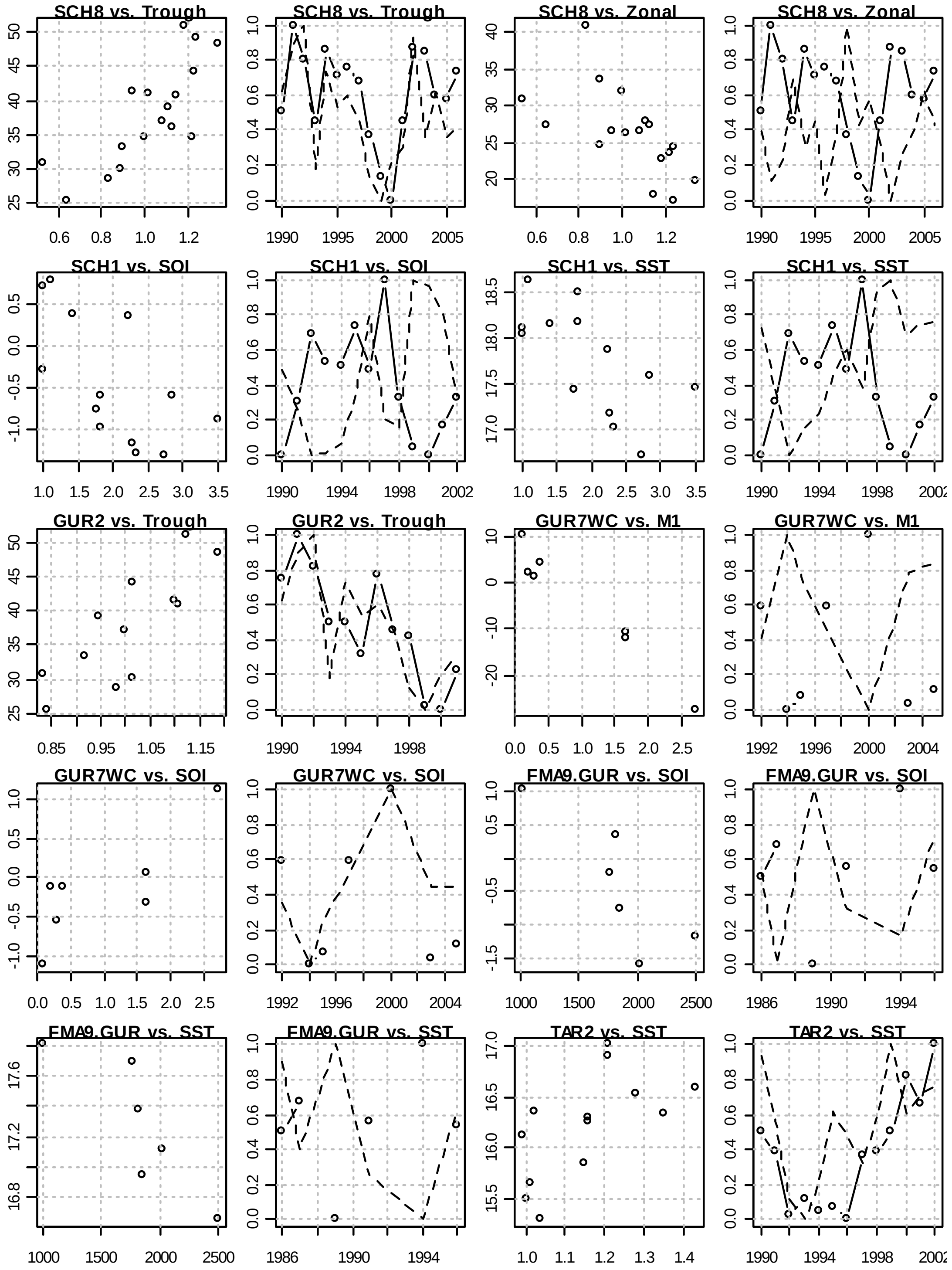

Figure 10: Relationships between fisheries and climate indices for selected species. Each correlation has two panels; the left panel is an x-y plot of the indices, the right panel is a time-series plot of the fisheries index (solid line) and climate index (broken line) on a common scale (between zero and 1).

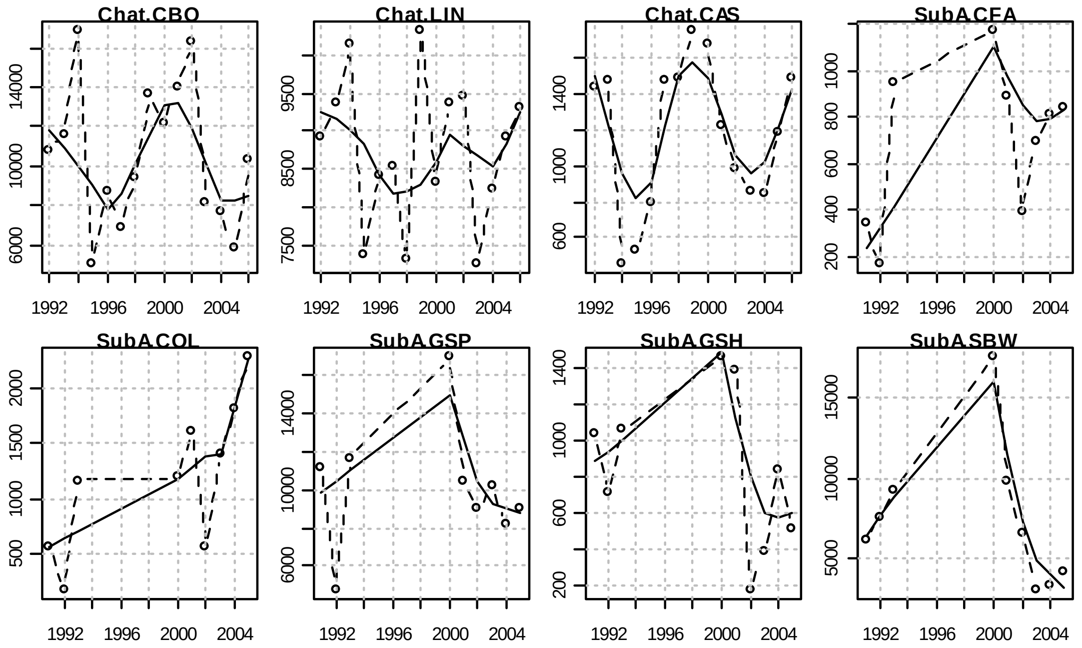

Figure 11: Selected biomass indices from the subantarctic (points and broken lines), with a loess smoother line added (solid line) to emphasize the overall trend.

An inverse relationship between red cod YCS and SST off the east and south coasts of the South Island (Beentjes & Renwick 2001) was also found off the west coast South Island, in addition to correlations with other climate variables, although this needs a longer time series to establish its validity.

The reported relationship for gemfish (Renwick et al. 1998) was unclear in this study. The hypothesised relationship between the invasion of the Peruvian jack mackerel (JMM) in the mid 1980s and the SOI could not be investigated because the only biomass index available was for the WCSI, and extended from 1992 to 2005.

4. CONCLUSIONS

Many of the rank correlations found in this study were as strong, or stronger than, those routinely reported in the scientific literature. Potentially interesting correlations were found for several species and stocks. Such correlations could be spurious, and a result of other changes (e.g., fishing mortality), and so further investigation is required to establish their validity. As a result, presenting hypotheses in this report for the mechanisms by which climate or environmental factors may influence these fish stocks would have been premature.

Francis (2006) found that the lengths of data series used in a sample of recent environment-recruitment studies varied between 6 and 60 years, with a median of 20 years. The length of the data series used here varied between 5 and 32 years, with a median of 9 years. Despite some predictor screening, the shortness of some data series makes it possible that some of the significant correlations found will be spurious, and some true relationships will not have been detected.

On the Chatham Rise, the time series was relatively long, and there were groups of species with remarkably similar biomass trends, some of which were significantly correlated with climate. Further work would be required to establish links (if any) between these species. Such links could be trophic, or related to smaller scale environmental features or variability. Only after this would it be appropriate to consider the potential hypotheses for climate effects on these species.

The attempts to use groups of cold and warm water species didn't produce interesting results, and didn't support the *a priori* hypotheses. Where potential effects (correlations) were identified, the direction of these was often inconsistent. It is therefore possible that either the species classification was wrong, or that species responses to climate are complex and not easily predictable. As they stand, the conclusions support no clear effect of climate on species approaching the limits of their range around New Zealand, and no common and widespread (in terms of species) abundance changes correlated with climate.

This study has provided initial correlations between climate and some species, but understanding of the mechanism and intermediate links is lacking. Information which would help future studies are a continued (longer) time series of data, and further and more appropriate environmental or climate indices (e.g., scale of upwelling, distribution and abundance of prey items, etc) on finer and more appropriate spatial or temporal scales. Further analyses could then also include a more detailed assessment of the reliability of the abundance or YCS indices (including ageing errors in the latter, for example), consideration of other factors that may have affected abundance (e.g., catch history), smaller-scale temporal and spatial variability in abundance, further statistical analysis of relationships (e.g., GLMs and cross-validation where times series are sufficiently long), leading to development of hypotheses for the climate relationships.

5. ACKNOWLEDGMENTS

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Zeldis, J. R., Oldman, J., Ballara, S. L. & Richards, L. A. (2005). Physical fluxes, pelagic ecosystem structure, and larval fish survival in Hauraki Gulf, New Zealand. *Canadian Journal of Fisheries and Aquatic Sciences 62*: 593–610.

APPENDIX A: Climate Data

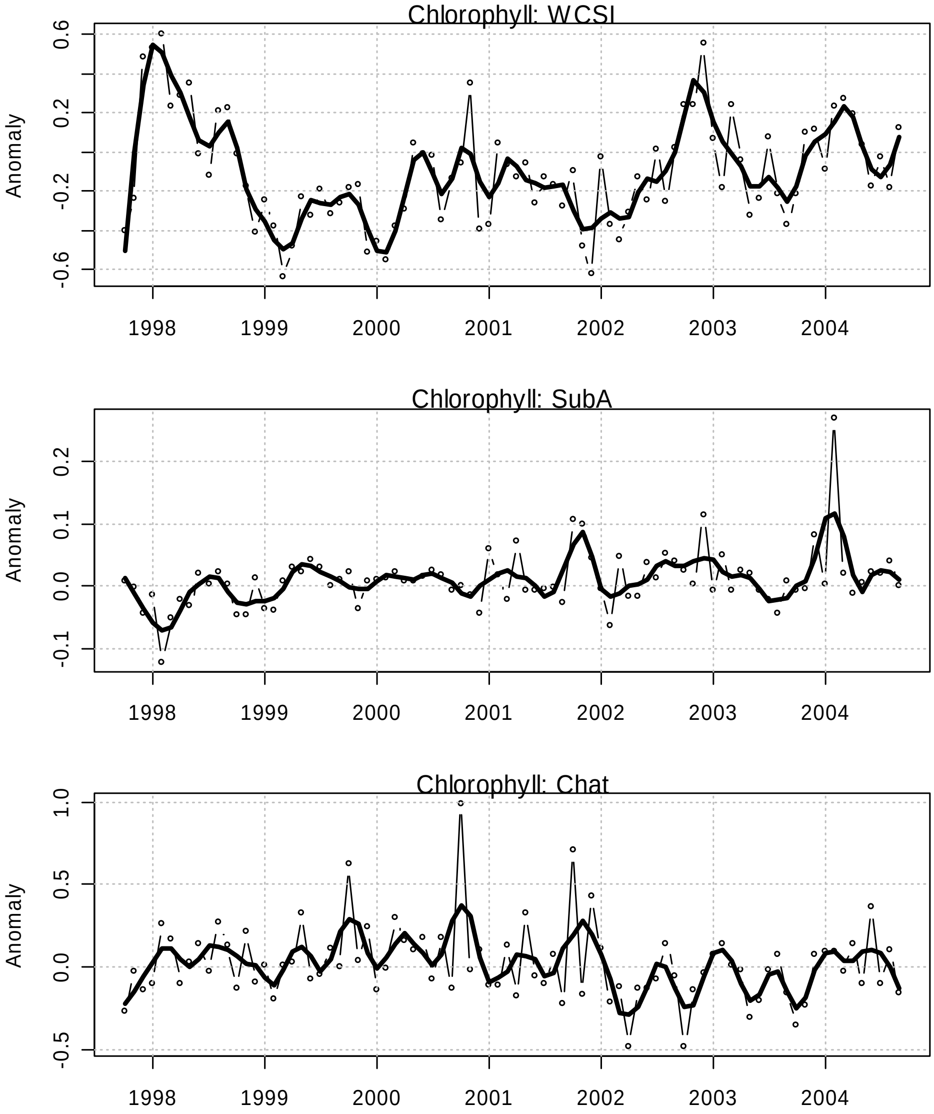


Figure A1: Monthly anomaly values for mean chlorophyll for: West Coast South Island (WCSI), SubAntarctic (SubA), and Chatham Rise (Chat). The data are shown by points, the thicker line is a loess smoother added to indicate trend.

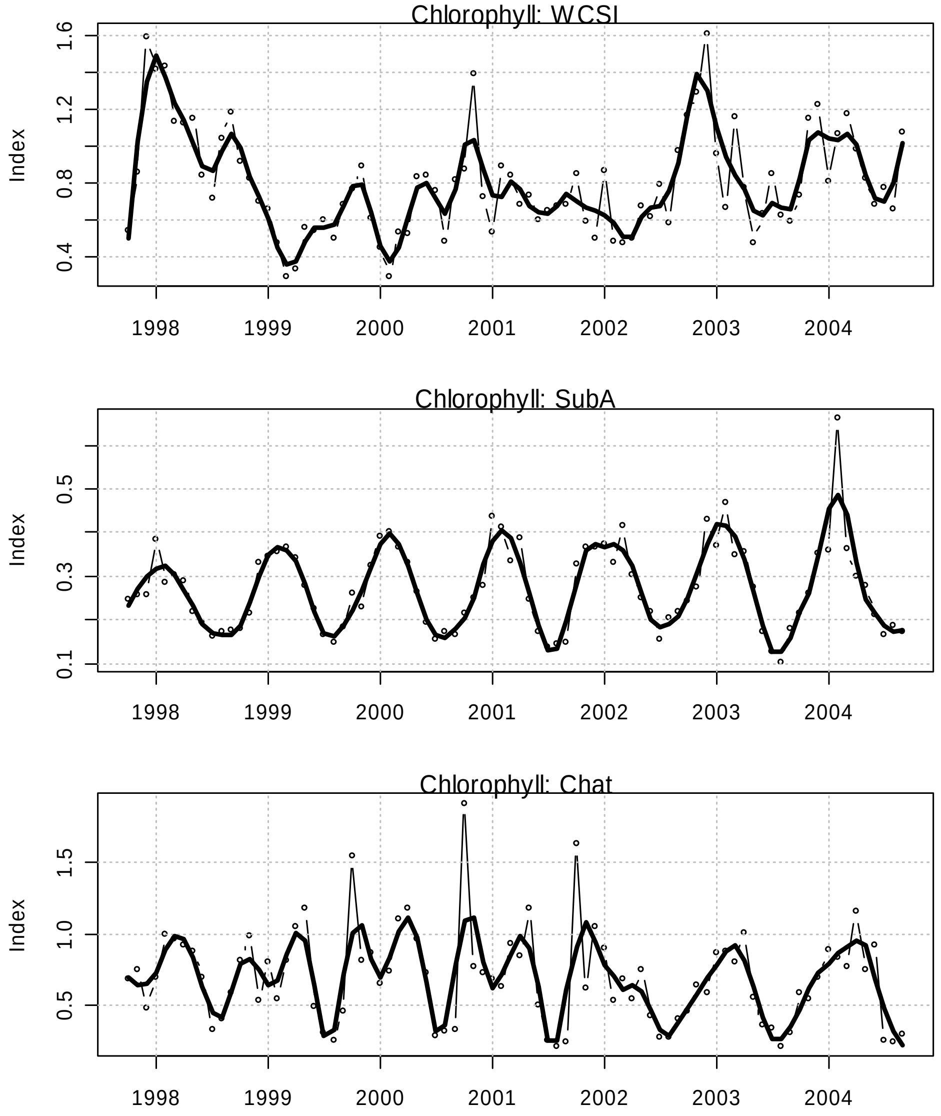


Figure A2: Monthly mean chlorophyll values for three regions: West Coast South Island (WCSI), SubAntarctic (SubA), and Chatham Rise (Chat). The data are shown by points, the thicker line is a loess smoother added to indicate trend.

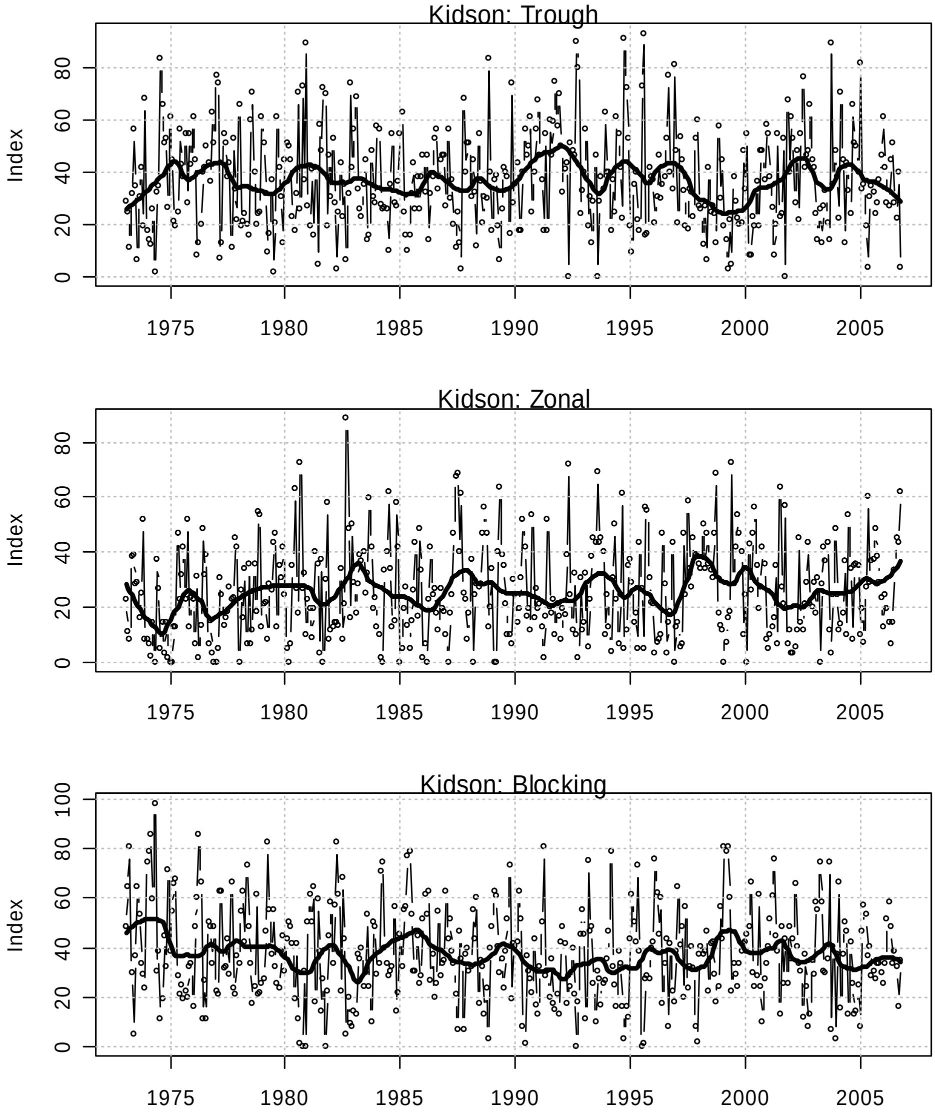


Figure A3: The monthly mean Kidson regime weather indices, "Trough", "Zonal" and "Blocking". The data are shown by points, the thicker line is a loess smoother added to indicate trend.

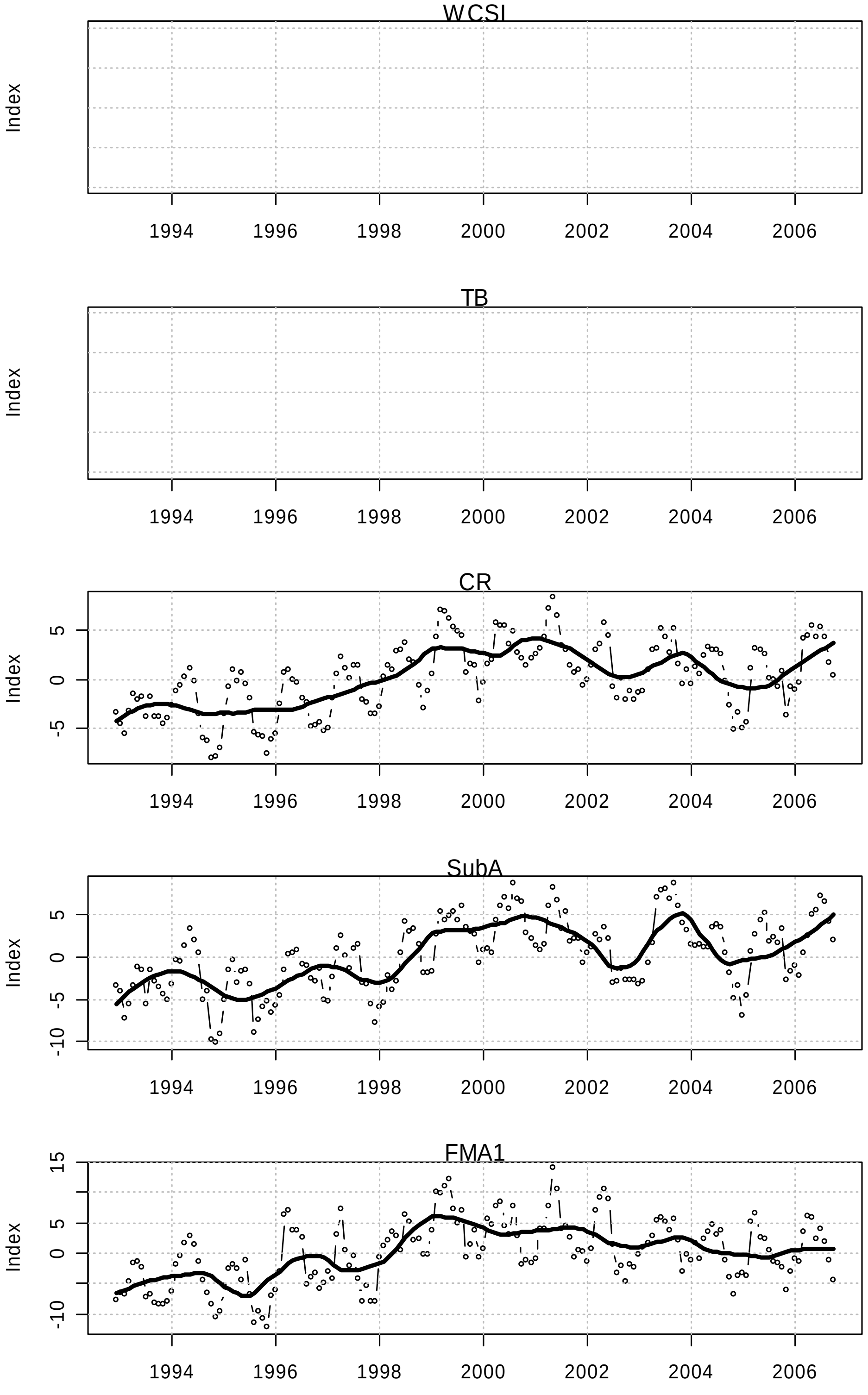


Figure A4: Monthly mean SSH for each fishery area. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

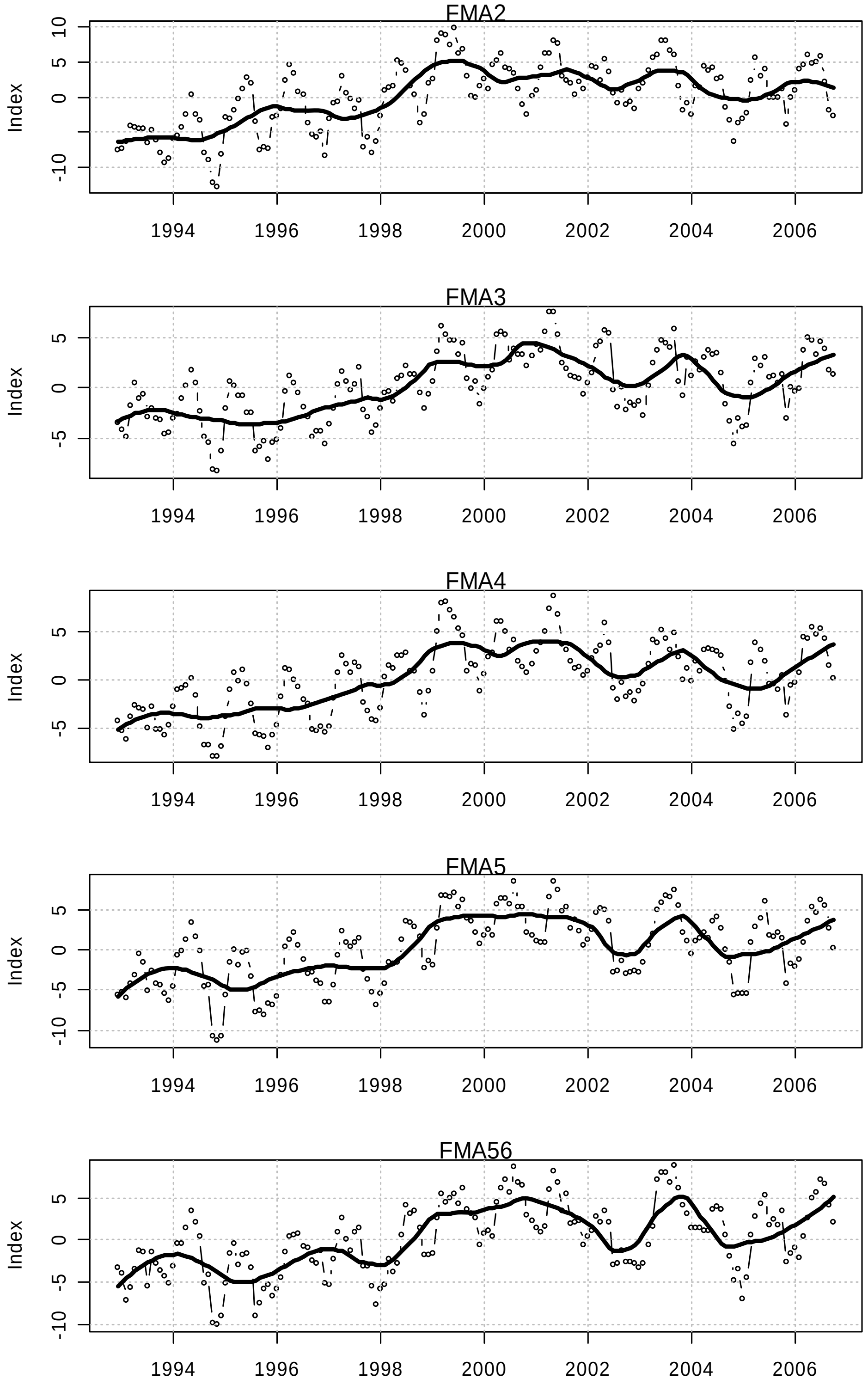


Figure A4 (cont.): Monthly mean SSH for each fishery area. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

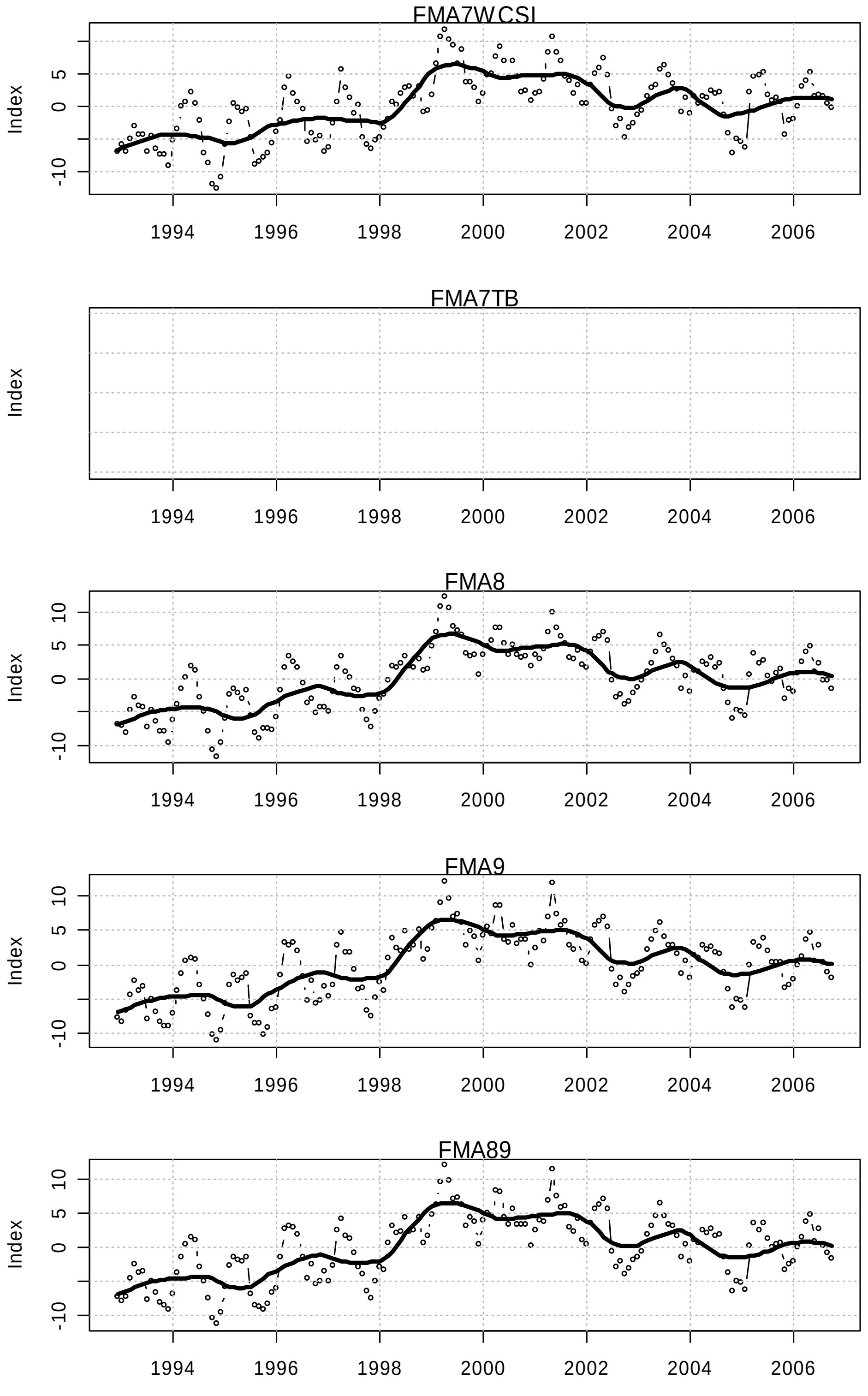


Figure A4 (cont.): Monthly mean SSH for each fishery area. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

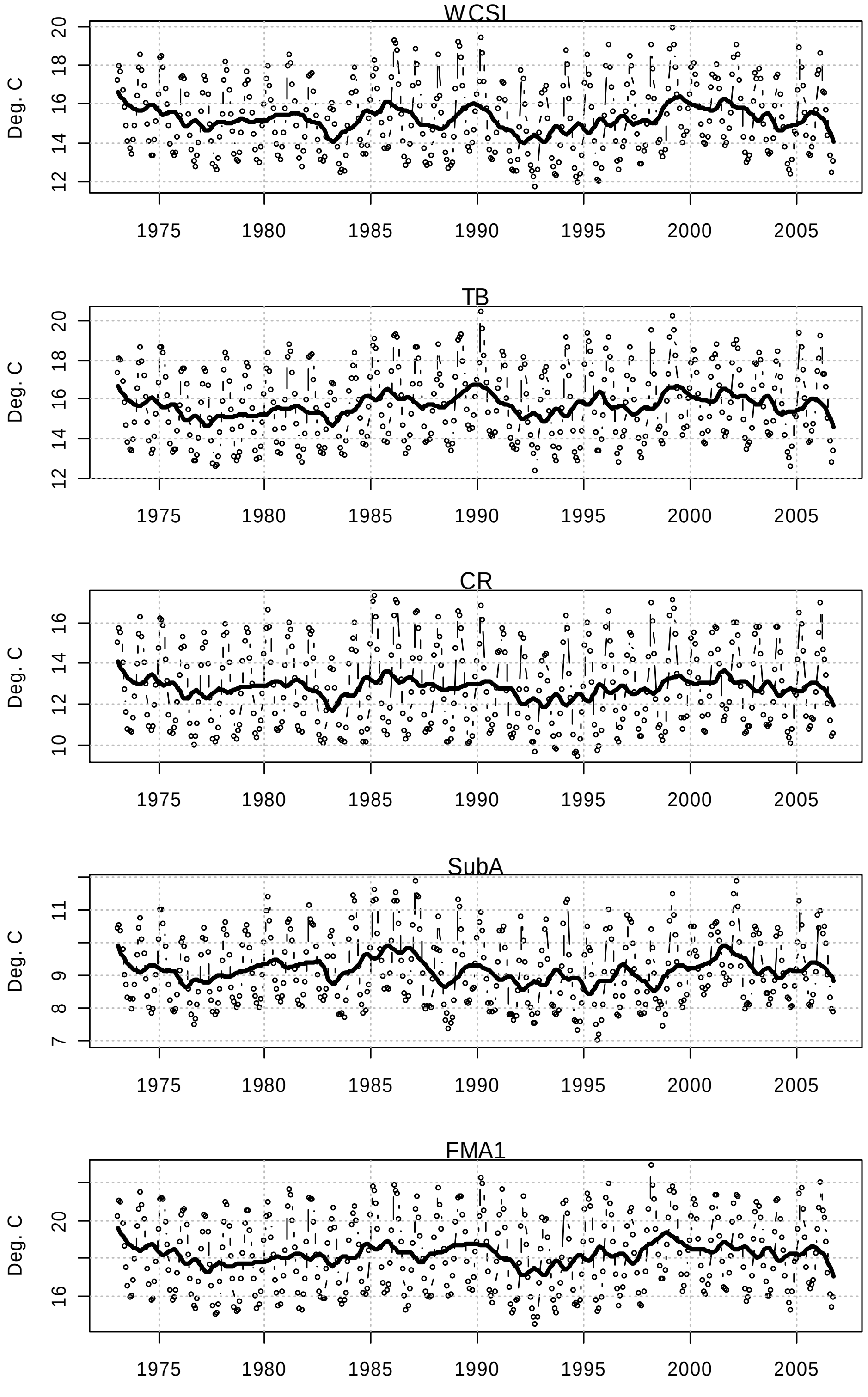


Figure A5: Monthly mean SST for each fishery area. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

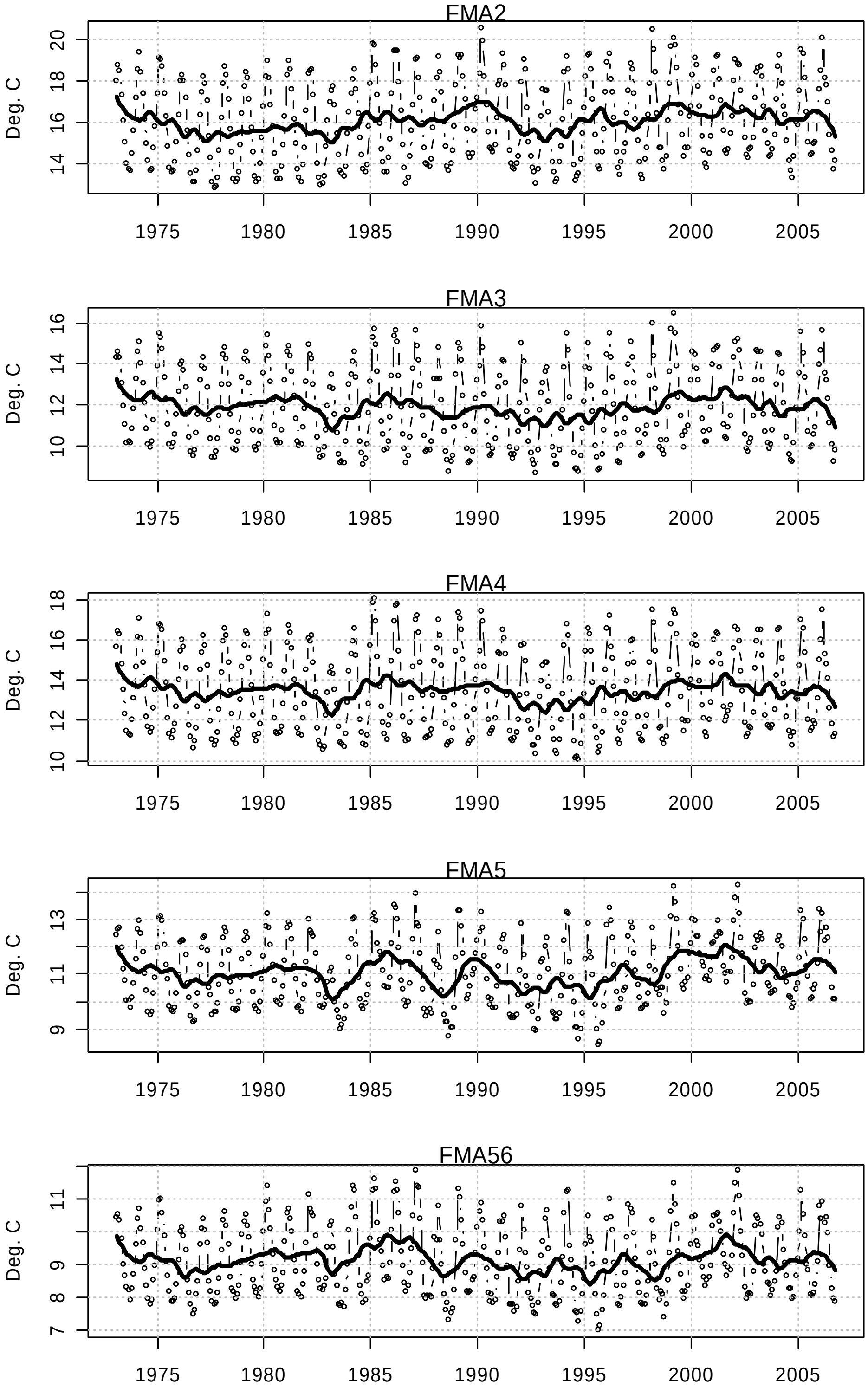


Figure A5 (cont.): Monthly mean SST for each fishery area. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

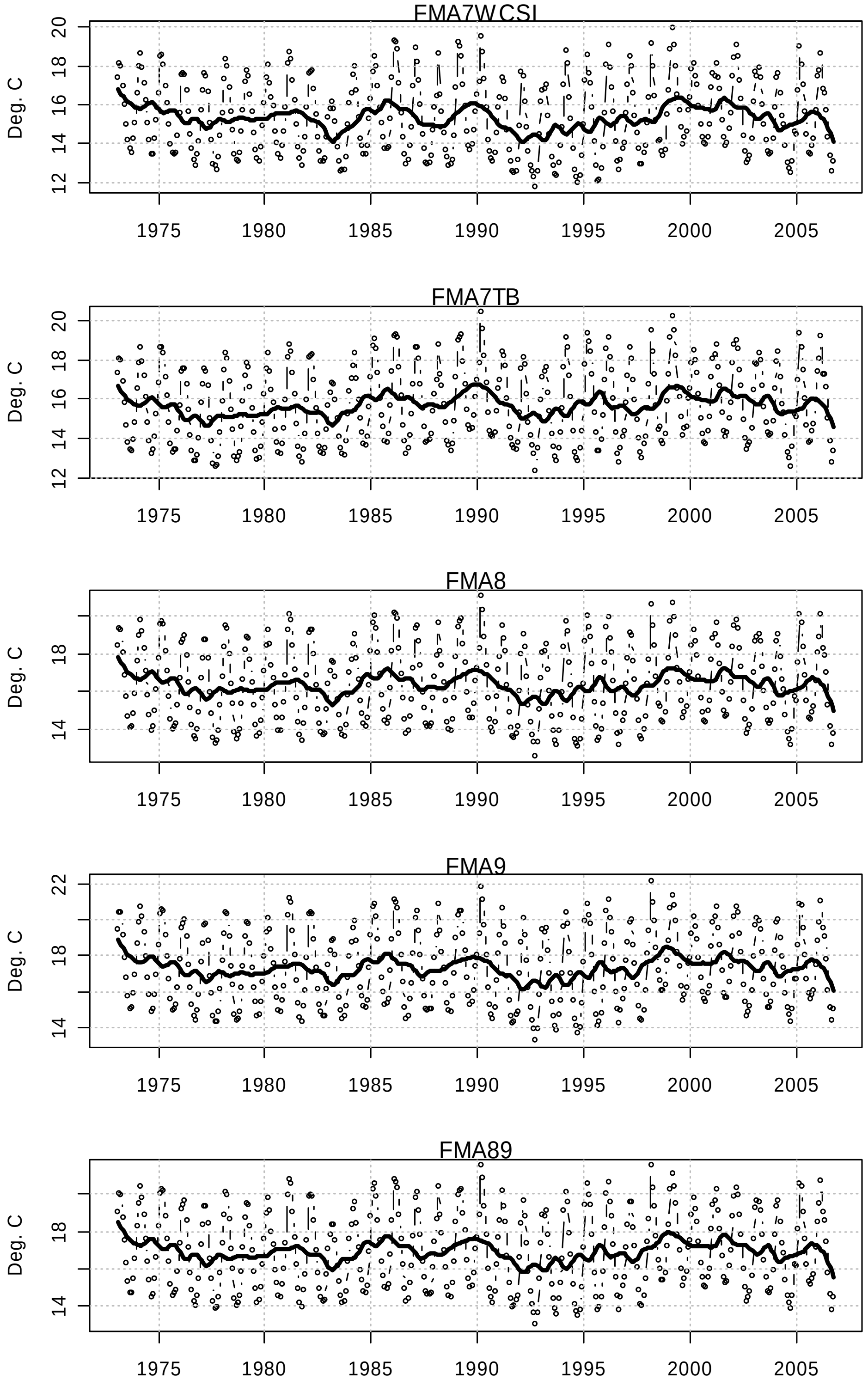


Figure A5 (cont.): Monthly mean SST for each fishery area. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

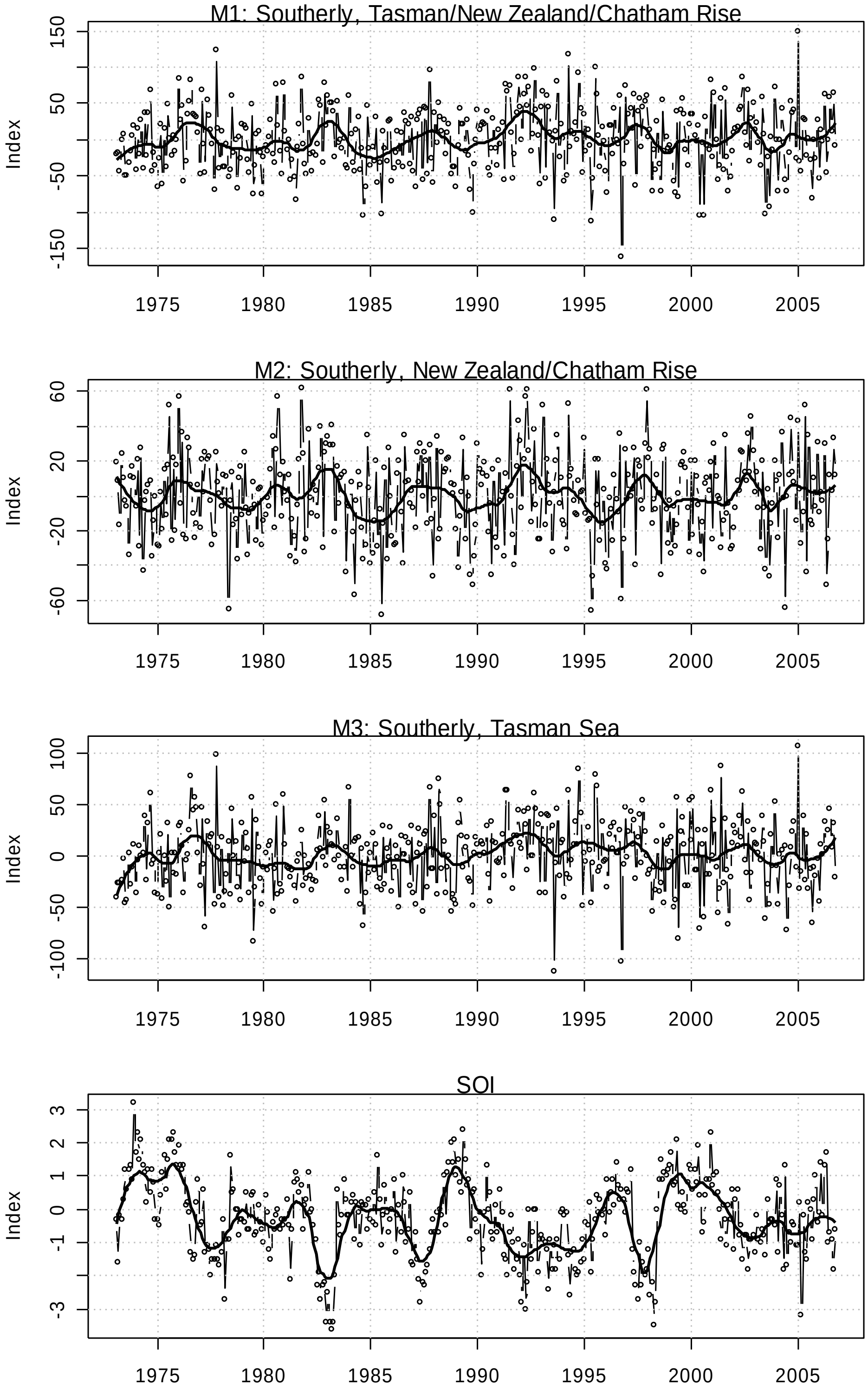


Figure A6: Monthly mean pressure indices (Trenberth indices, and SOI), and for Trenberth indices the wind direction and area to which the apply. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

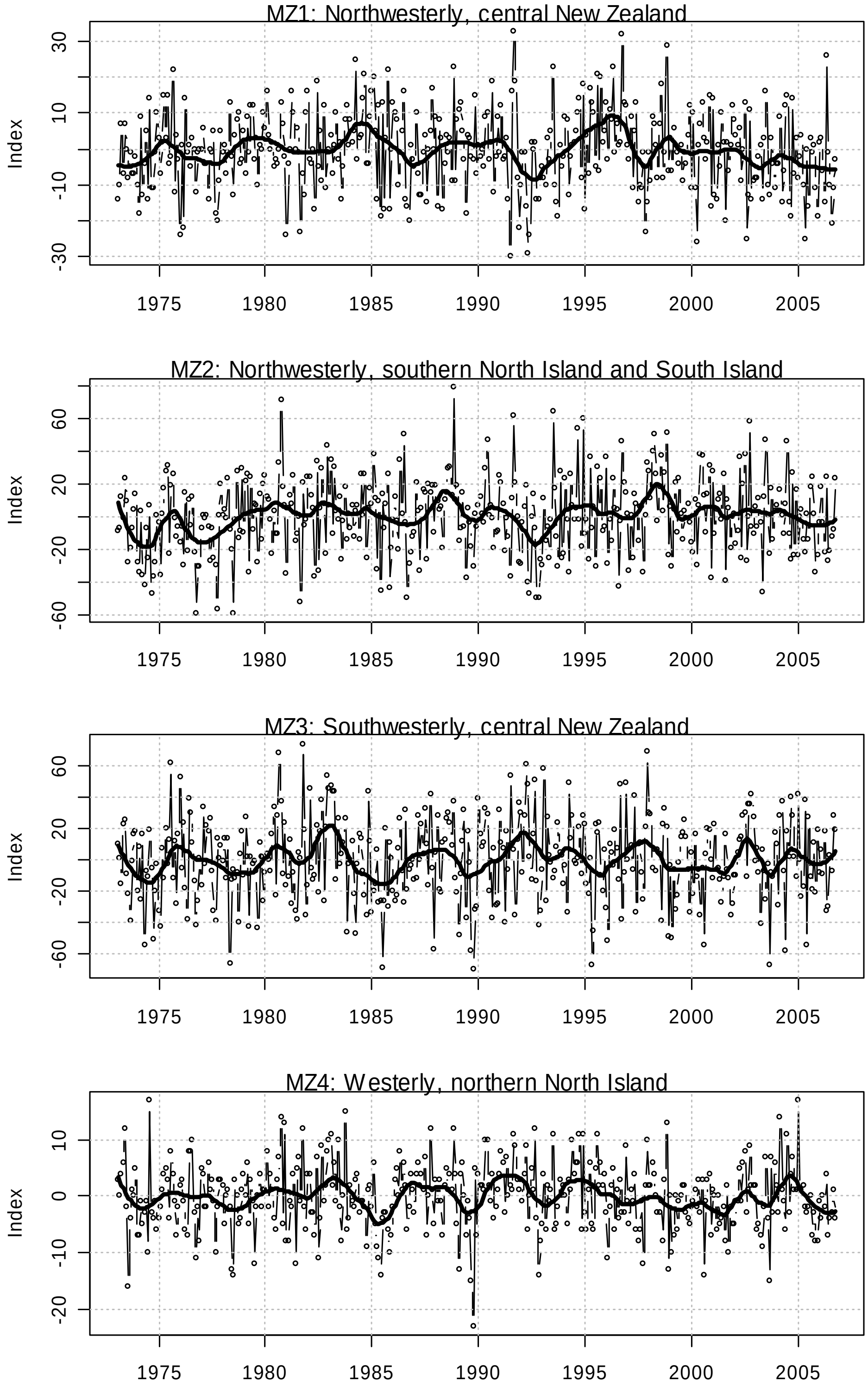


Figure A6 (cont.): Monthly mean pressure indices (Trenberth indices, and SOI), and for Trenberth indices the wind direction and area to which the apply. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

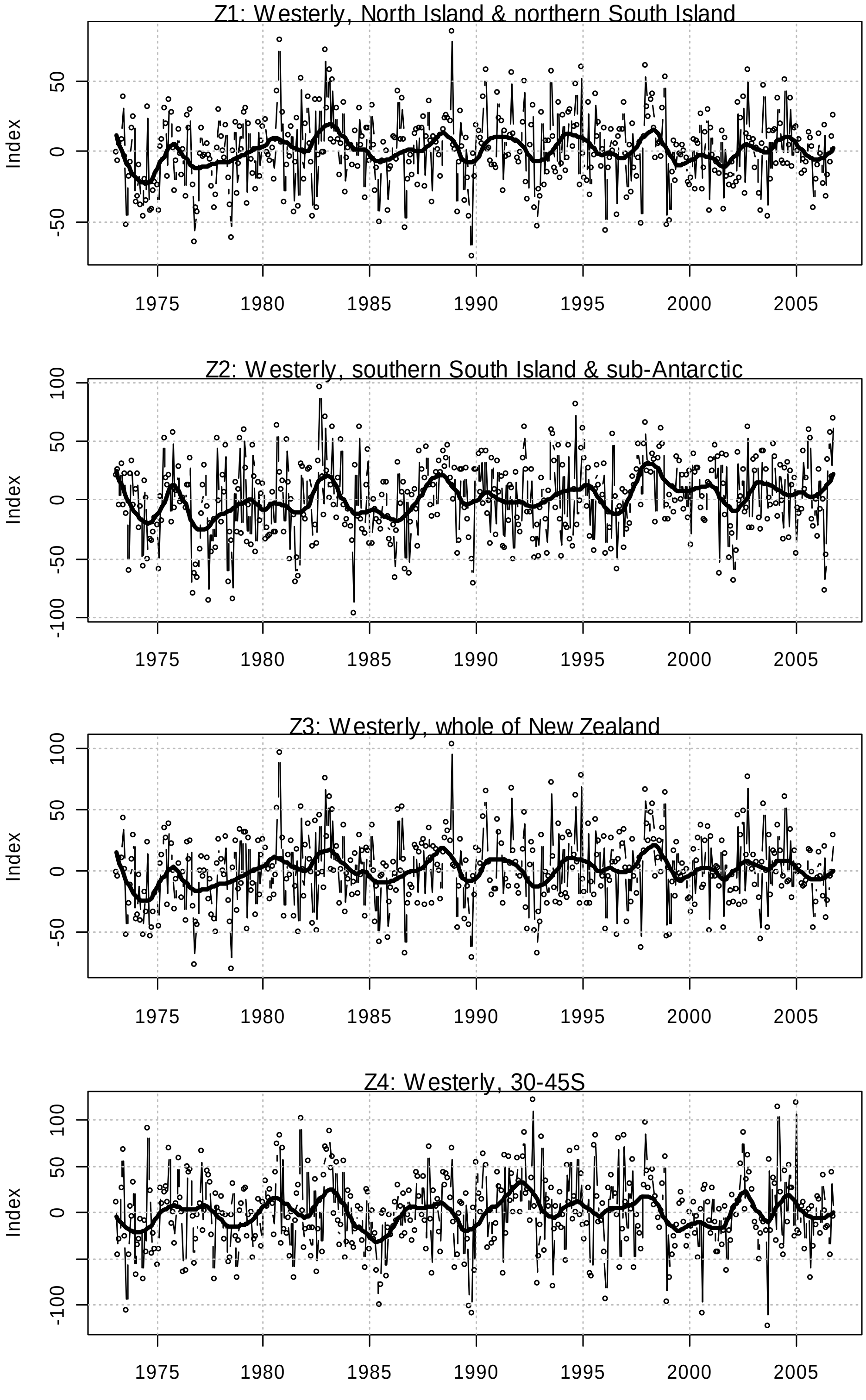
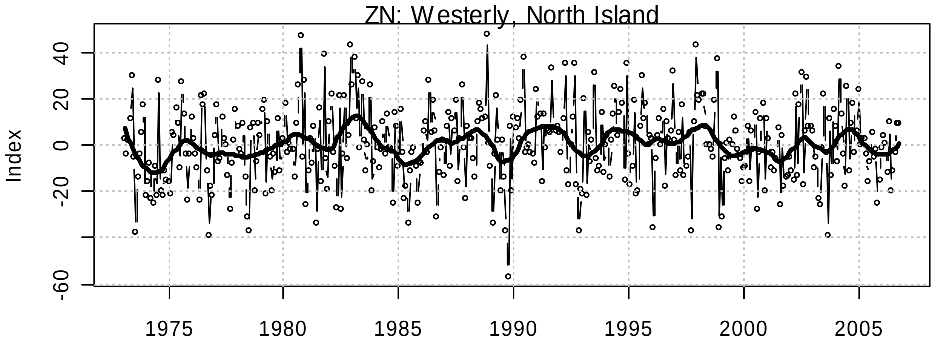


Figure A6 (cont.): Monthly mean pressure indices (Trenberth indices, and SOI), and for Trenberth indices the wind direction and area to which the apply. The data are shown by points, the thicker line is a loess smoother added to indicate trend.



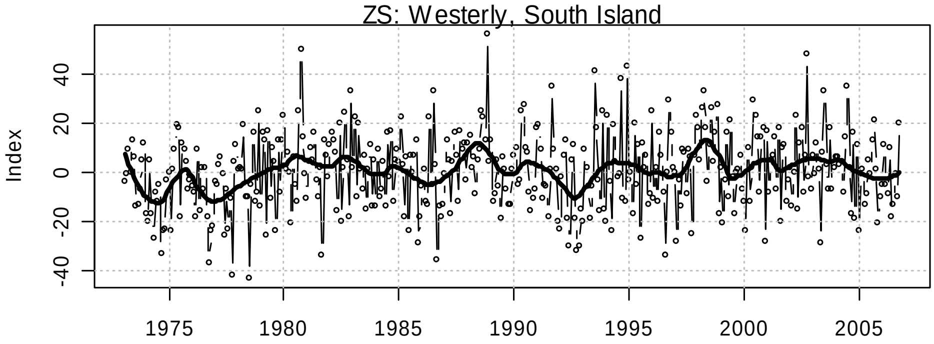
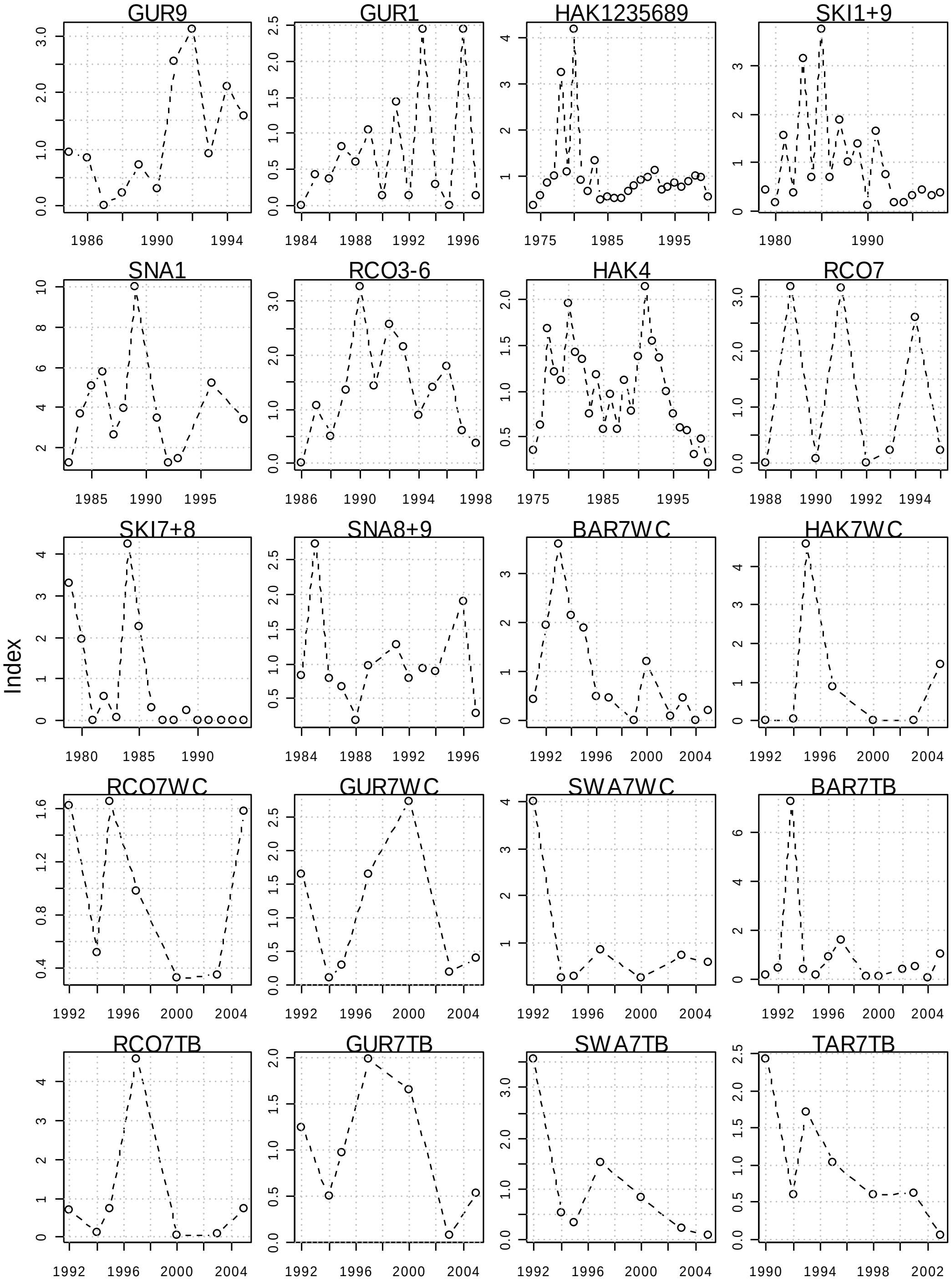
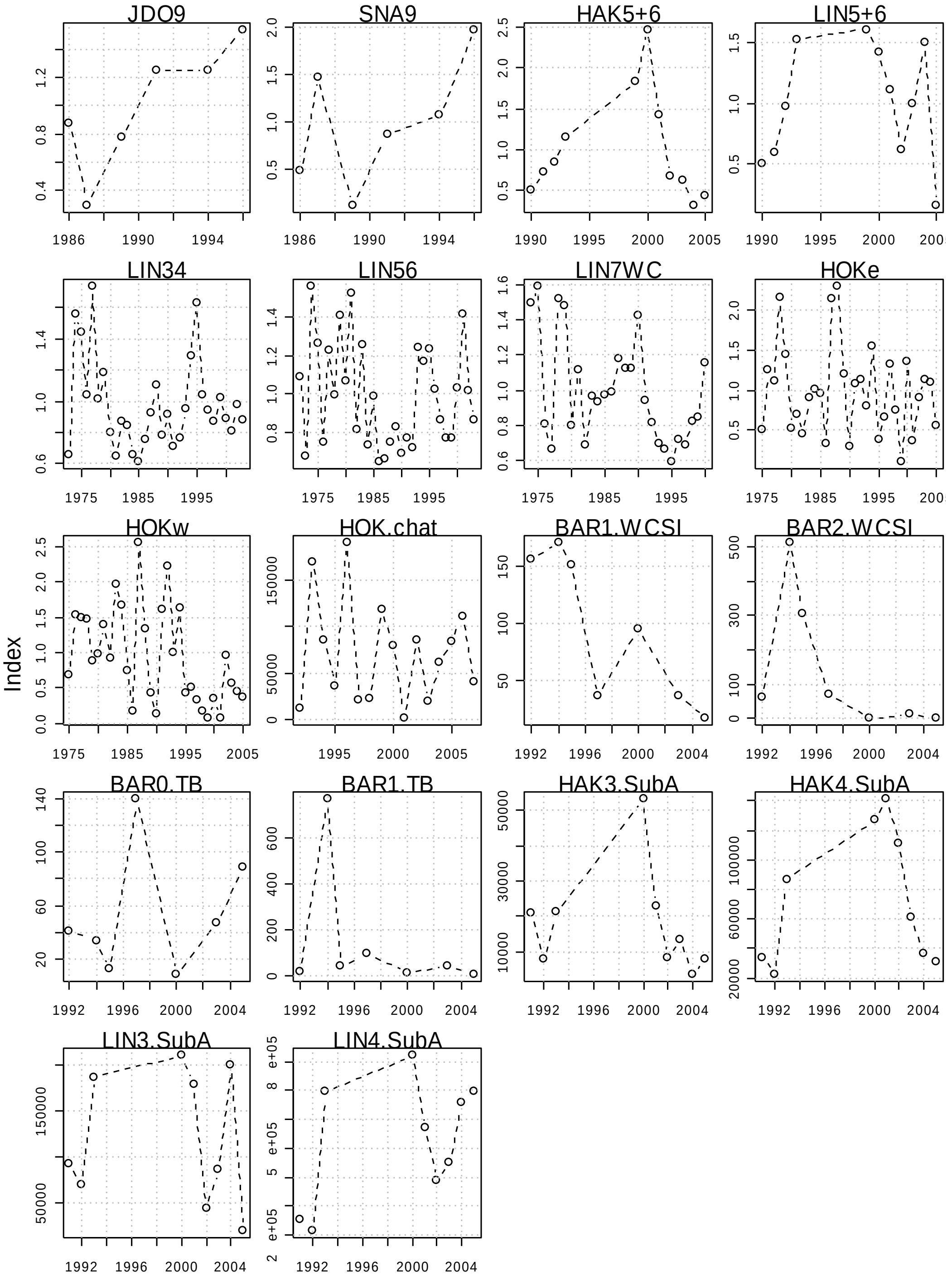


Figure A6 (cont.): Monthly mean pressure indices (Trenberth indices, and SOI), and for Trenberth indices the wind direction and area to which the apply. The data are shown by points, the thicker line is a loess smoother added to indicate trend.

APPENDIX B: Fisheries Data

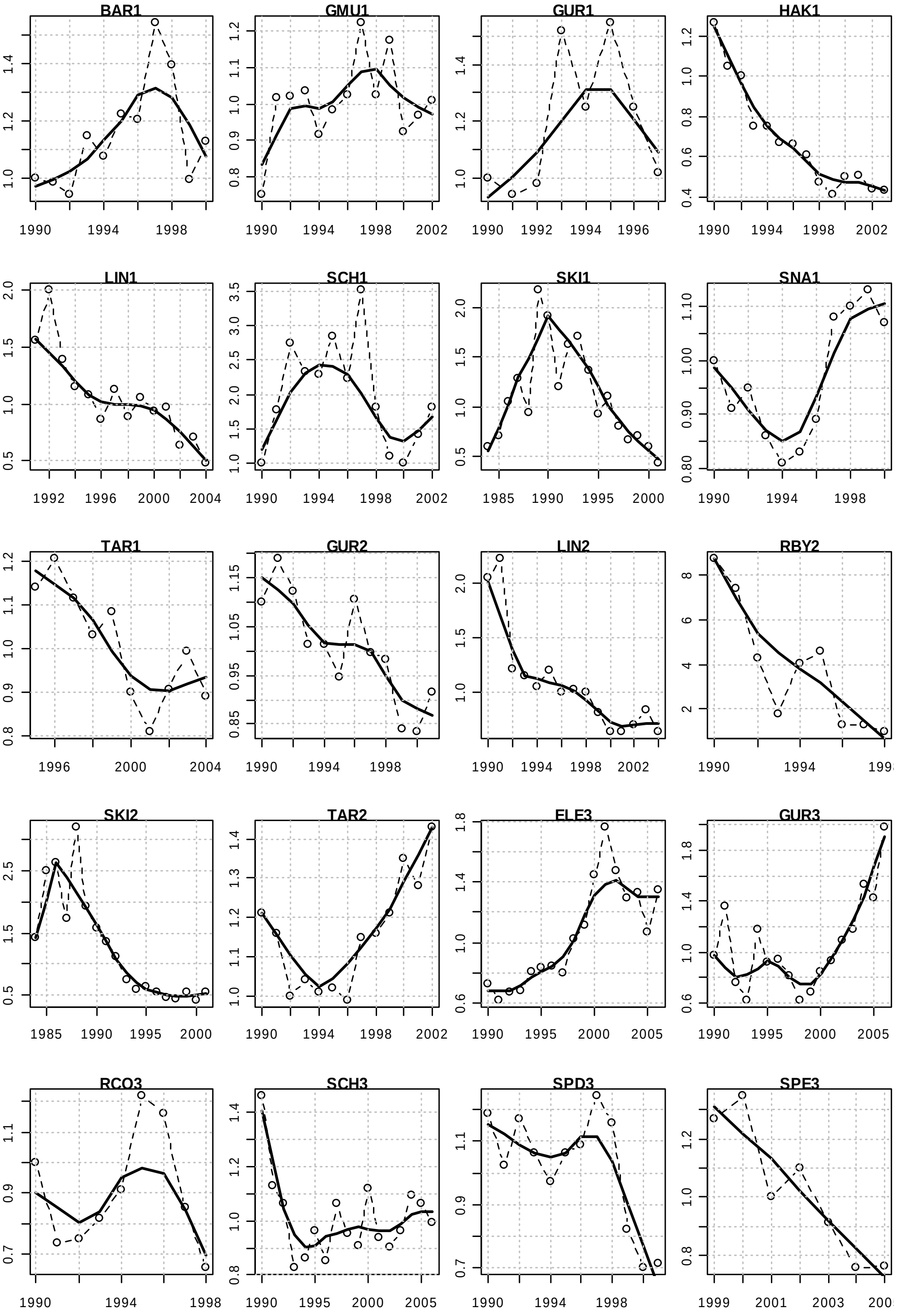
B1: Year Class Strength Indices

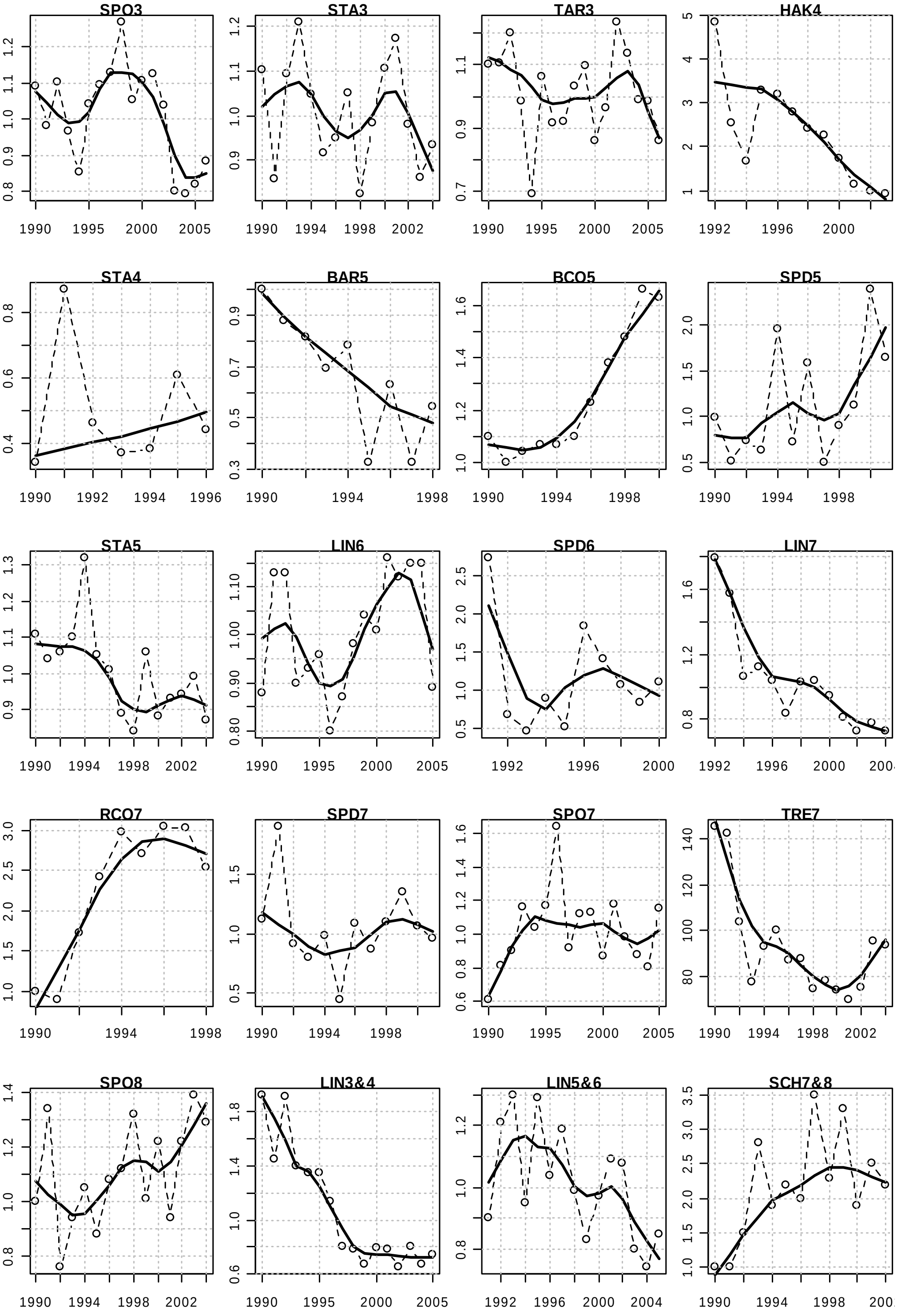


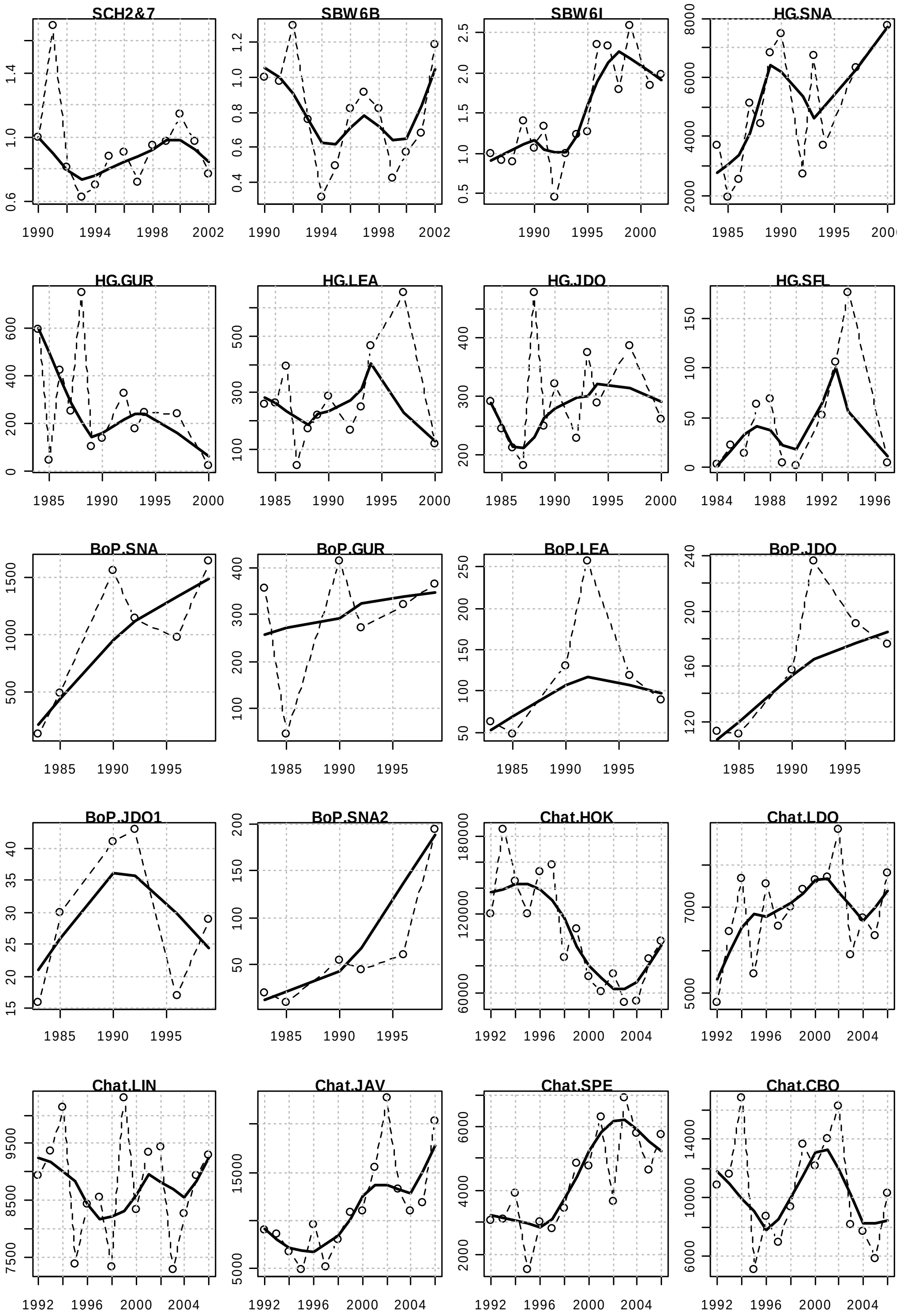

Index
JDO9
0.4
0.8
1.2
1986
1990
1994
SNA9
0.5
1.0
1.5
2.0
1986
1990
1994
HAK5+6
0.5
1.0
1.5
2.0
2.5
1990
1995
2000
2005
LIN5+6
0.5
1.0
1.5
1990
1995
2000
200
LIN34
0.6
1.0
1.4
1975
1985
1995
LIN56
0.8
1.0
1.2
1.4
1975
1985
1995
LIN7WC
0.6
0.8
1.0
1.2
1.4
1.6
1975
1985
1995
HOKe
0.5
1.0
1.5
2.0
1975
1985
1995
200
HOKw
0.0
0.5
1.0
1.5
2.0
2.5
1975
1985
1995
2005
HOK.chat
0
50000
150000
1995
2000
2005
BAR1.WCSI
50
100
150
1992
1996
2000
2004
BAR2.WCSI
0
100
300
500
1992
1996
2000
2004
BAR0.TB
20
60
100
140
1992
1996
2000
2004
BAR1.TB
0
200
400
600
1992
1996
2000
2004
HAK3.SubA
10000
30000
50000
1992
1996
2000
2004
HAK4.SubA
20000
60000
100000
1992
1996
2000
2004
LIN3.SubA
50000
150000
1992
1996
2000
2004
LIN4.SubA
2 e+05
5 e+05
8 e+05
1992
1996
2000
2004

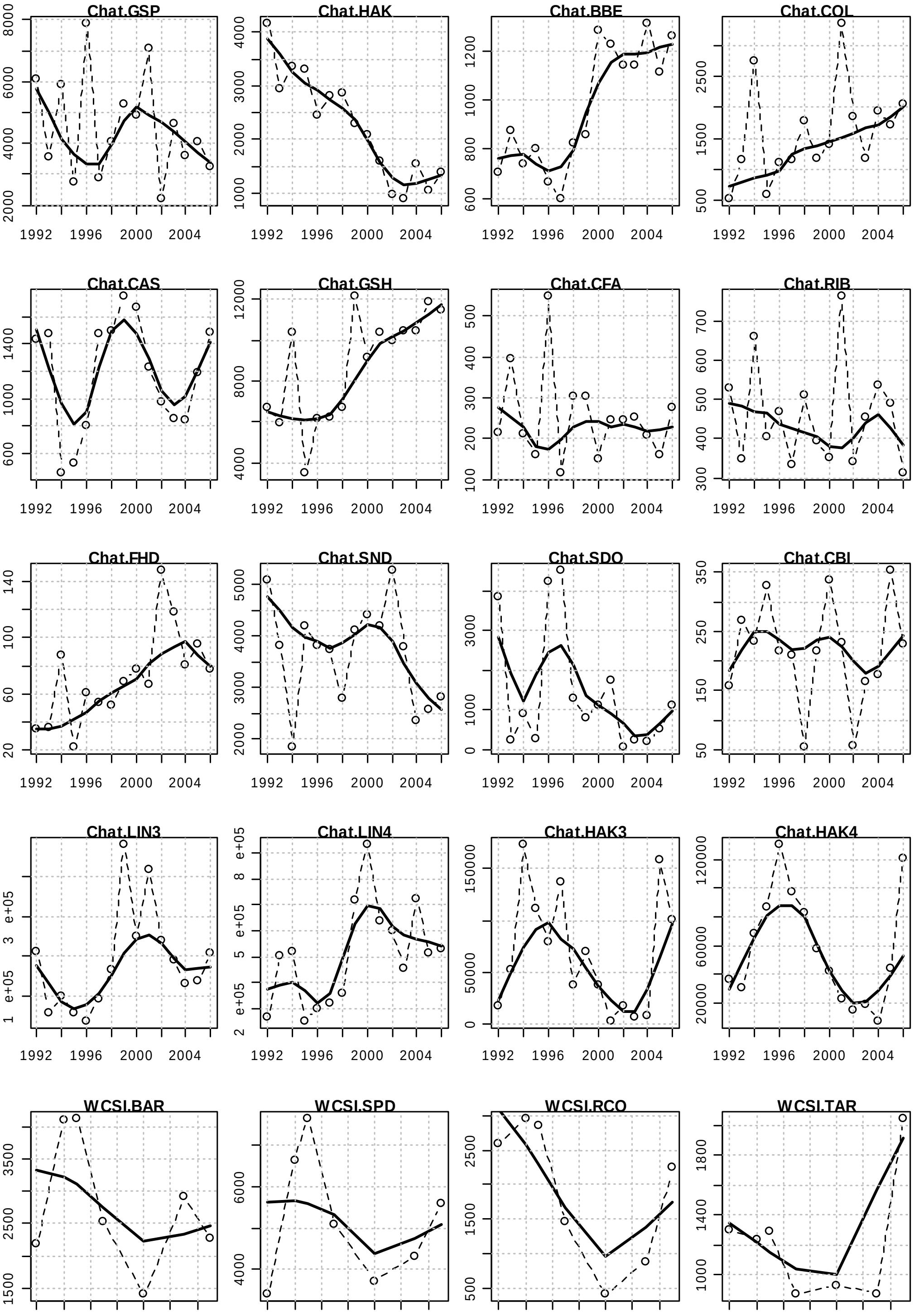
B2: Biomass Indices

The data are shown by points, the thicker line is a loess smoother added to indicate trend. The loess smoother was also used when the index was taken as an index of year class strength.




SPO3
0.8
0.9
1.0
1.1
1.2
1990
1995
2000
2005
STA3
0.9
1.0
1.1
1.2
1990
1994
1998
2002
TAR3
0.7
0.9
1.1
1990
1995
2000
2005
HAK4
1
2
3
4
5
1992
1996
2000
STA4
0.4
0.6
0.8
1990
1992
1994
1996
BAR5
0.3
0.5
0.7
0.9
1990
1994
1998
BCO5
1.0
1.2
1.4
1.6
1990
1994
1998
SPD5
0.5
1.0
1.5
2.0
1990
1994
1998
STA5
0.9
1.0
1.1
1.2
1.3
1990
1994
1998
2002
LIN6
0.80
0.90
1.00
1.10
1990
1995
2000
2005
SPD6
0.5
1.0
1.5
2.0
2.5
1992
1996
2000
LIN7
0.8
1.2
1.6
1992
1996
2000
RCO7
1.0
1.5
2.0
2.5
3.0
1990
1994
1998
SPD7
0.5
1.0
1.5
1990
1994
1998
SPO7
0.6
0.8
1.0
1.2
1.4
1.6
1990
1995
2000
2005
TRE7
80
100
120
140
1990
1994
1998
2002
SPO8
0.8
1.0
1.2
1.4
1990
1994
1998
2002
LIN3&4
0.6
1.0
1.4
1.8
1990
1995
2000
2005
LIN5&6
0.8
1.0
1.2
1992
1996
2000
2004
SCH7&8
1.0
1.5
2.0
2.5
3.0
3.5
1990
1994
1998


SCH2&7
0.6 1.0 1.4
1990 1994 1998 2002
SBW6B
0.4 0.6 0.8 1.0 1.2
1990 1994 1998 2002
SBW6I
0.5 1.0 1.5 2.0 2.5
1990 1995 2000
HG.SNA
2000 4000 6000 8000
1985 1990 1995 200
HG.GUR
0 200 400 600
1985 1990 1995 2000
HG.LEA
100 300 500
1985 1990 1995 2000
HG.JDO
200 300 400
1985 1990 1995 2000
HG.SFL
0 50 100 150
1984 1988 1992 1996
BoP.SNA
500 1000 1500
1985 1990 1995
BoP.GUR
100 200 300 400
1985 1990 1995
BoP.LEA
50 100 150 200 250
1985 1990 1995
BoP.JDO
120 160 200 240
1985 1990 1995
BoP.JDO1
15 20 25 30 35 40
1985 1990 1995
BoP.SNA2
50 100 150 200
1985 1990 1995
Chat.HOK
60000 120000 180000
1992 1996 2000 2004
Chat.LDO
5000 7000
1992 1996 2000 2004
Chat.LIN
7500 8500 9500
1992 1996 2000 2004
Chat.JAV
5000 15000
1992 1996 2000 2004
Chat.SPE
2000 4000 6000
1992 1996 2000 2004
Chat.CBO
6000 10000 14000
1992 1996 2000 2004


Chat.GSP
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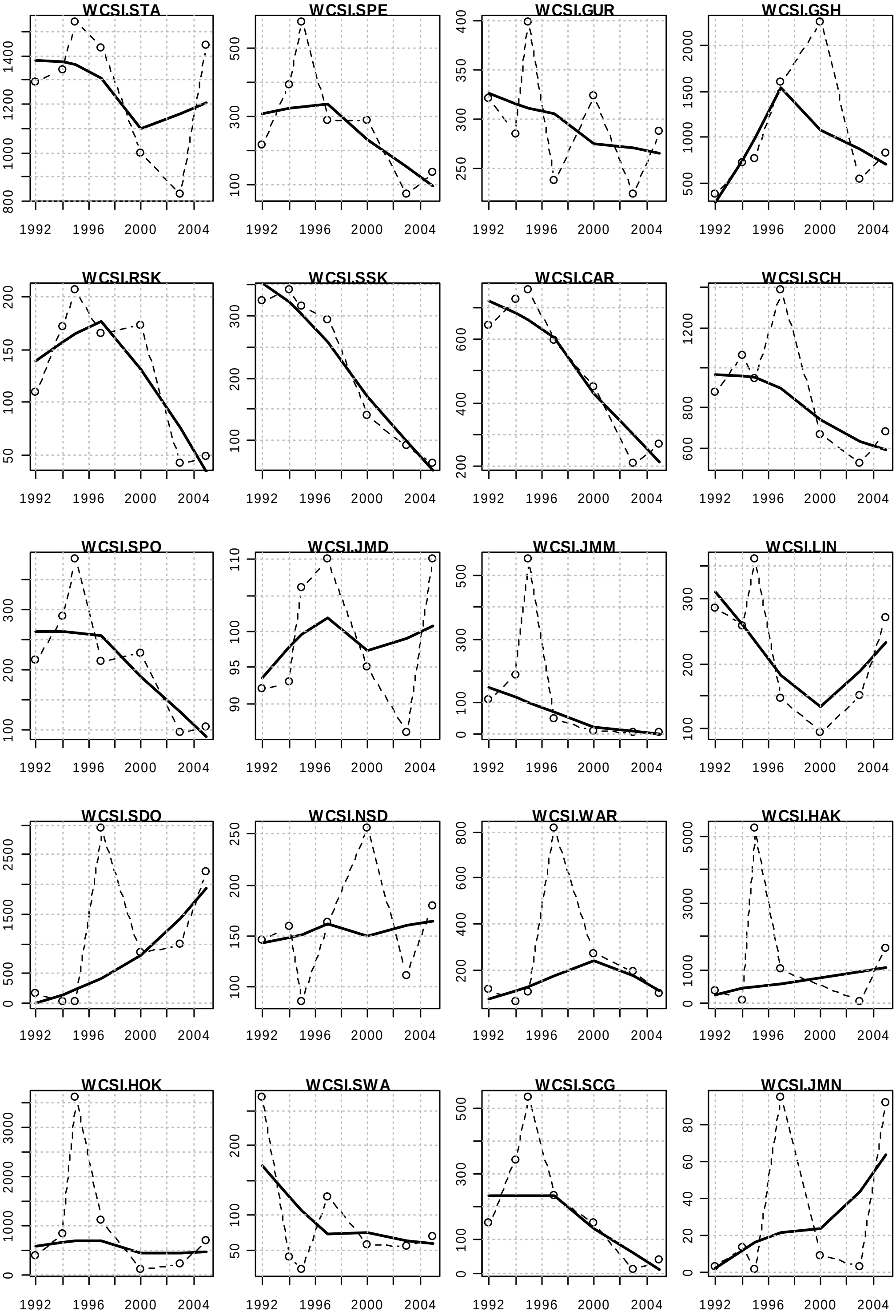
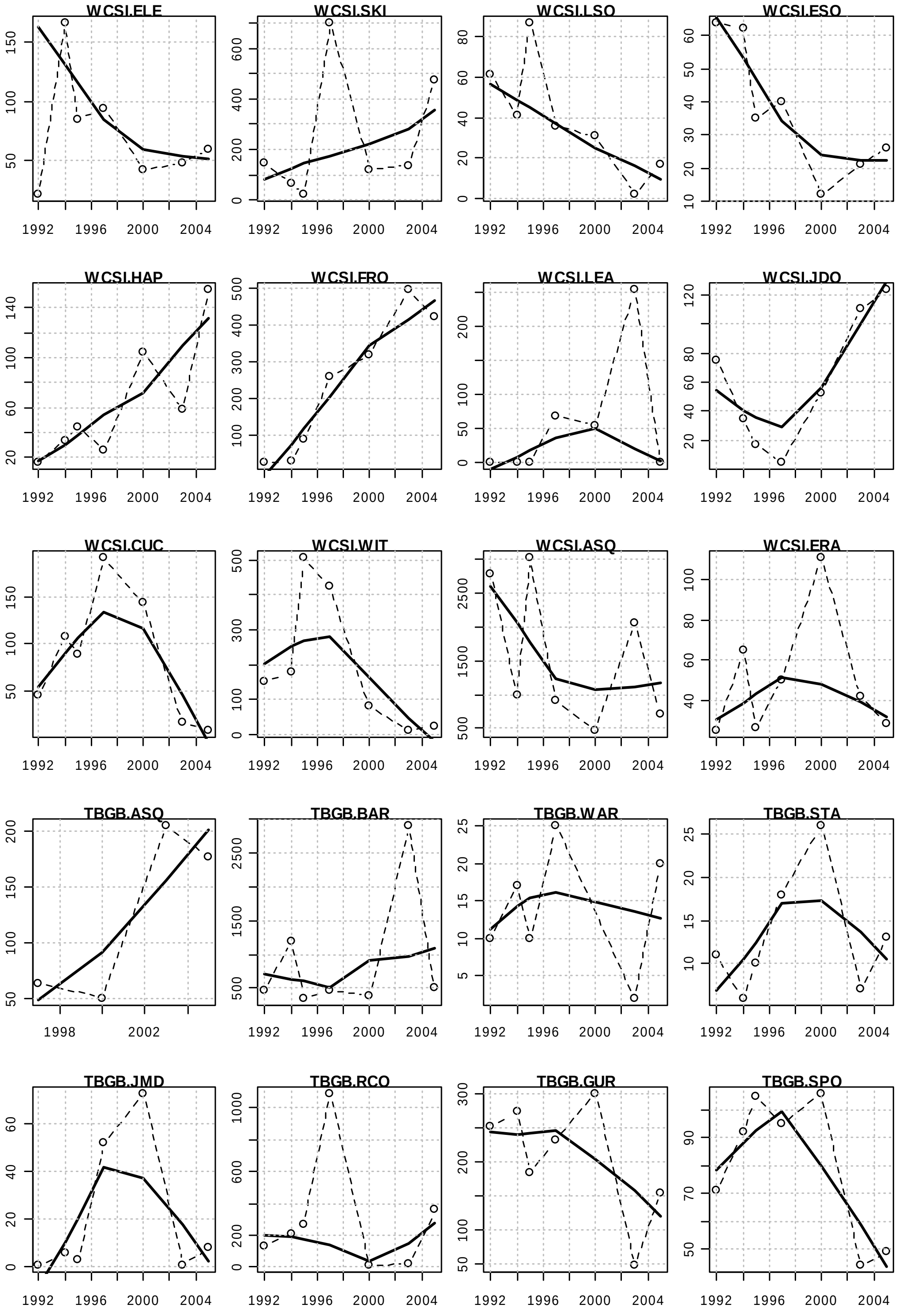
Chat.HAK
1000 2000 3000 4000
Chat.BBE
600 800 1000 1200
Chat.COL
500 1500 2500
Chat.CAS
600 1000 1400
Chat.GSH
4000 8000 12000
Chat.CFA
100 200 300 400 500
Chat.RIB
300 400 500 600 700
Chat.FHD
20 60 100 140
Chat.SND
2000 3000 4000 5000
Chat.SDO
0 1000 3000
Chat.CBI
50 150 250 350
Chat.LIN3
1 e+05 3 e+05
Chat.LIN4
2 e+05 5 e+05 8 e+05
Chat.HAK3
0 50000 150000
Chat.HAK4
20000 60000 120000
WCSI.BAR
1500 2500 3500
WCSI.SPD
4000 6000
WCSI.RCO
500 1500 2500
WCSI.TAR
1000 1400 1800
1992 1996 2000 2004



WCSI.STA
WCSI.SPE
WCSI.GUR
WCSI.GSH
WCSI.RSK
WCSI.SSK
WCSI.CAR
WCSI.SCH
WCSI.SPO
WCSI.JMD
WCSI.JMM
WCSI.LIN
WCSI.SDO
WCSI.NSD
WCSI.WAR
WCSI.HAK
WCSI.HOK
WCSI.SWA
WCSI.SCG
WCSI.JMN
1992
1996
2000
2004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100
150
1992
1996
2000
2004
WCSI.SKI
0
200
400
600
1992
1996
2000
2004
WCSI.LSO
0
20
40
60
80
1992
1996
2000
2004
WCSI.ESO
10
20
30
40
50
60
1992
1996
2000
2004
WCSI.HAP
20
60
100
140
1992
1996
2000
2004
WCSI.FRO
100
200
300
400
500
1992
1996
2000
2004
WCSI.LEA
0
50
100
200
1992
1996
2000
2004
WCSI.JDO
20
40
60
80
120
1992
1996
2000
2004
WCSI.CUC
50
100
150
1992
1996
2000
2004
WCSI.WIT
0
100
300
500
1992
1996
2000
2004
WCSI.ASQ
500
1500
2500
1992
1996
2000
2004
WCSI.ERA
40
60
80
100
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2000
2004
TBGB.WAR
5
10
15
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25
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1996
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2004
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15
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25
1992
1996
2000
2004
TBGB.JMD
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60
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1996
2000
2004
TBGB.RCO
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200
600
1000
1992
1996
2000
2004
TBGB.GUR
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1996
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2004
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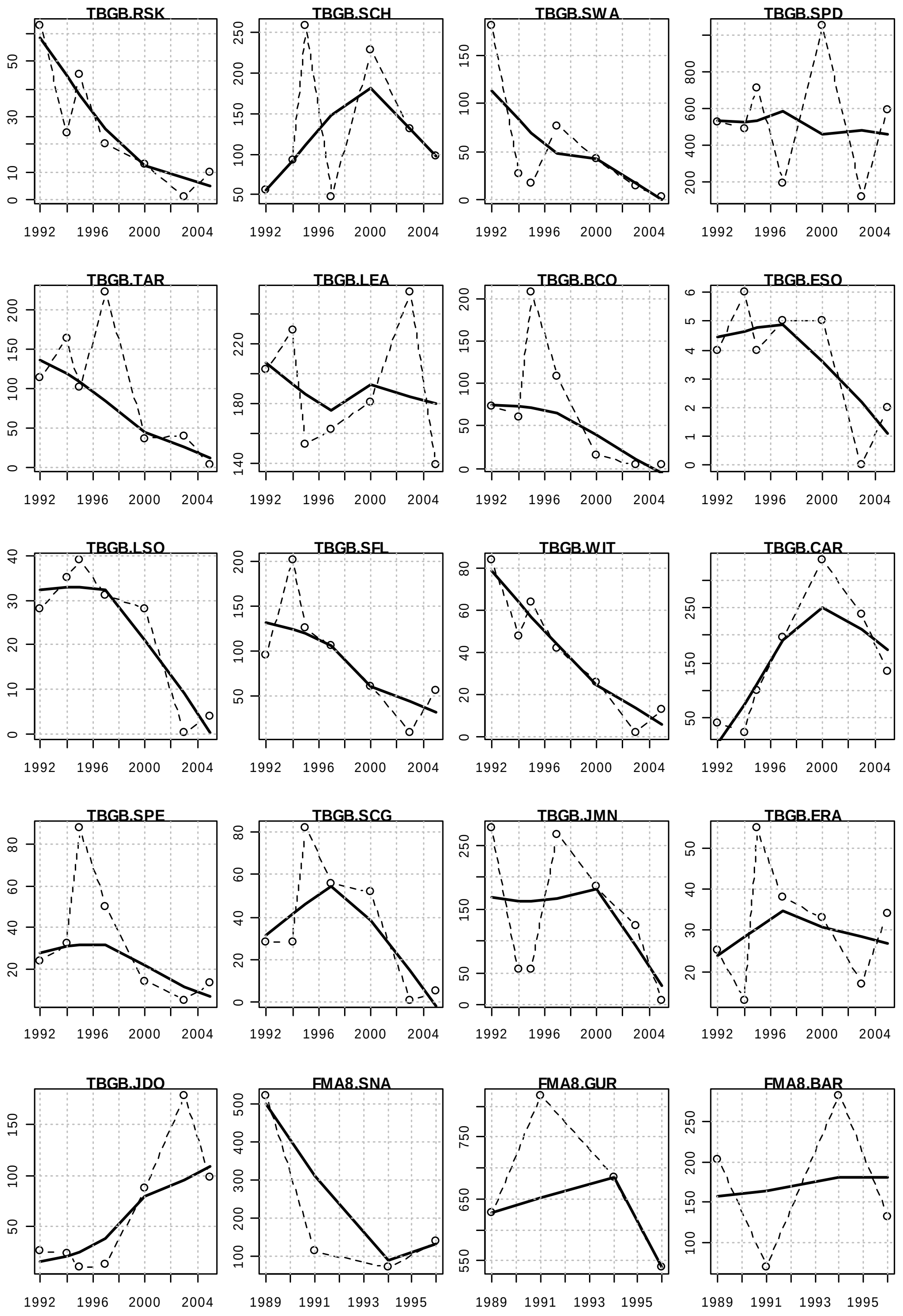
70
90
1992
1996
2000
2004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TBGB.ESO
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TBGB.SFL
TBGB.WIT
TBGB.CAR
TBGB.SPE
TBGB.SCG
TBGB.JMN
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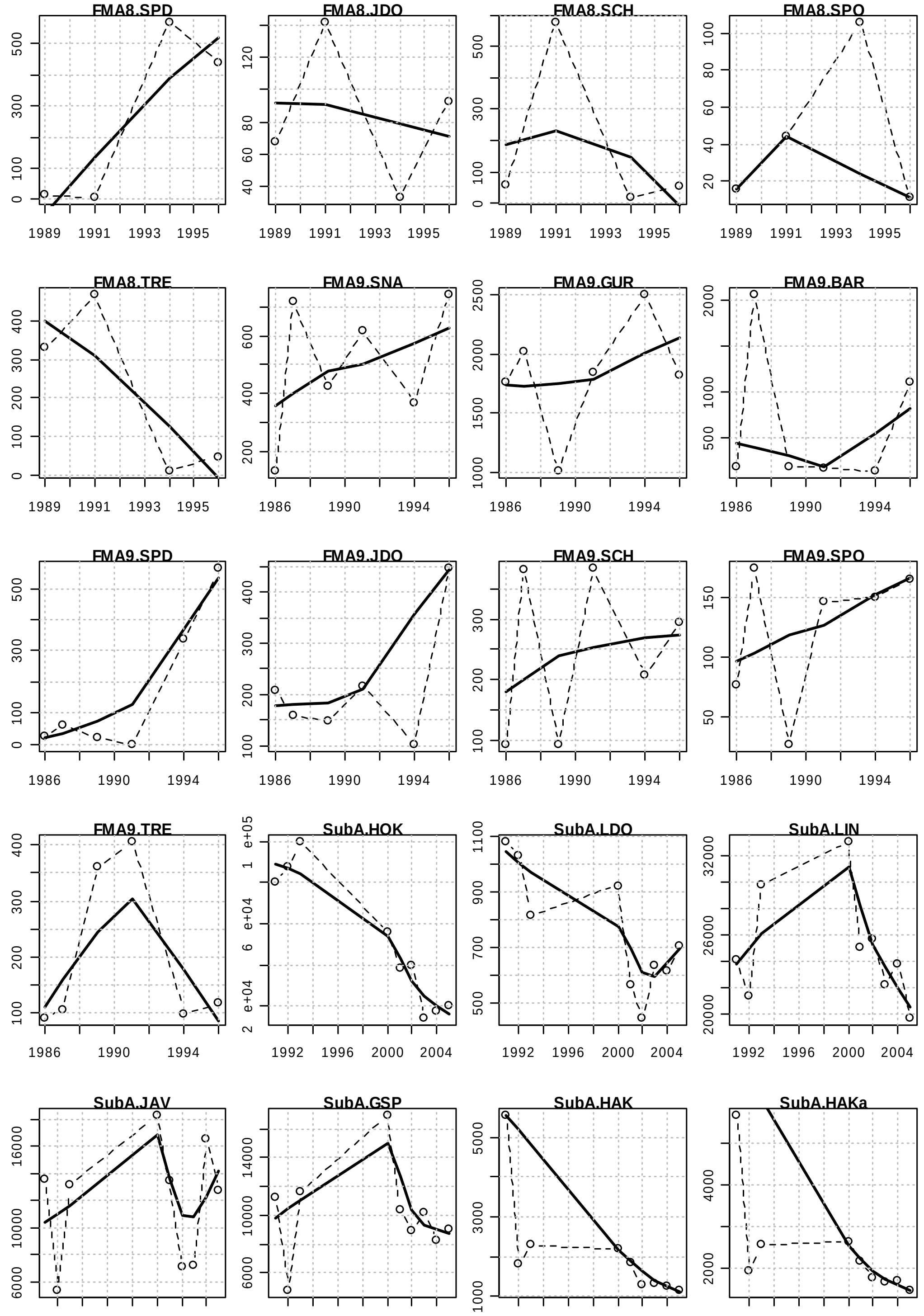
TBGB.JDO
FMA8.SNA
FMA8.GUR
FMA8.BAR
1992
1996
2000
2004
1989
1991
1993
1995


FMA8.SPD
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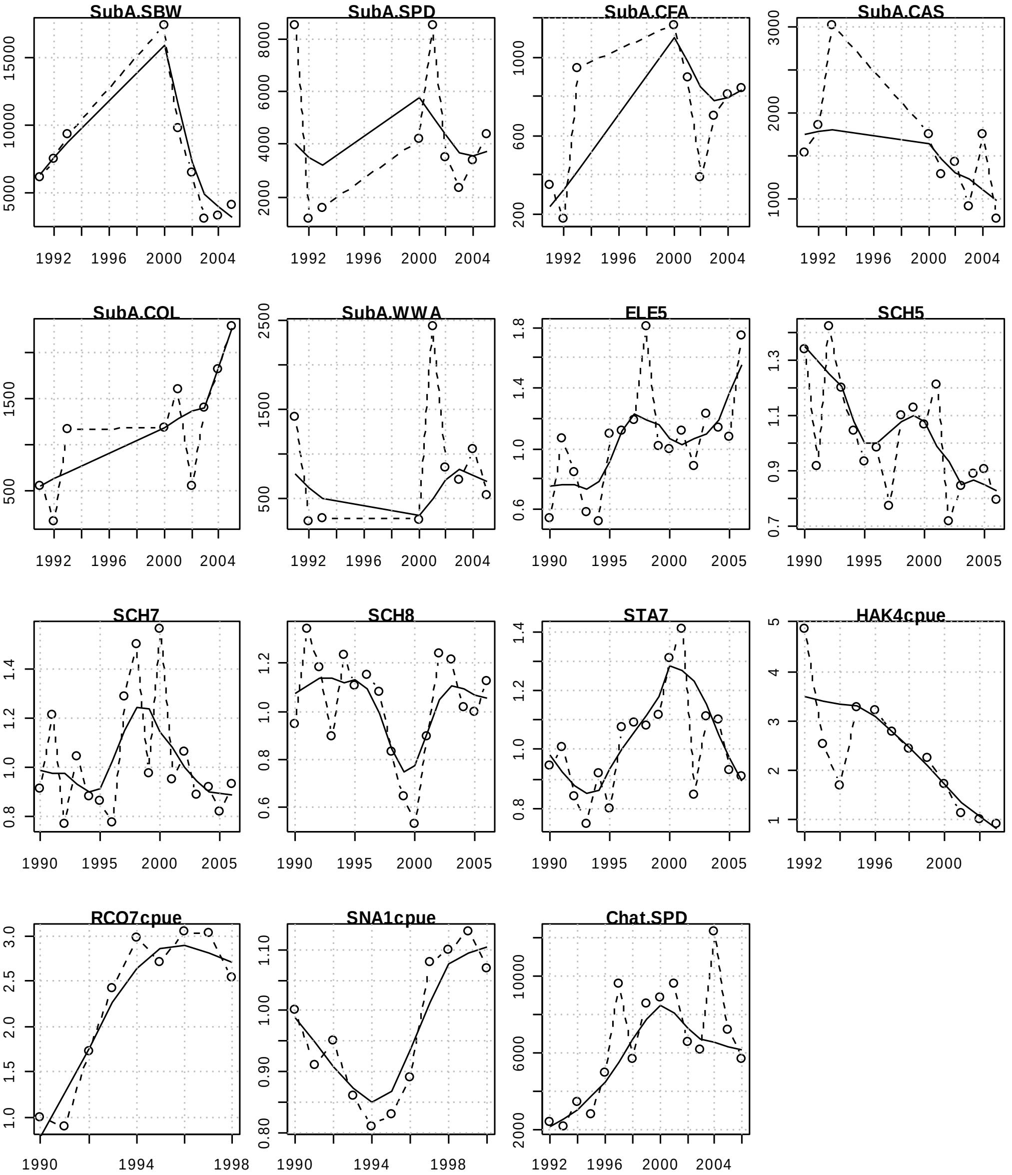
1989 1991 1993 1995
FMA8.JDO
40 60 80 120
1989 1991 1993 1995
FMA8.SCH
0 100 300 500
1989 1991 1993 1995
FMA8.SPO
20 40 60 80 100
1989 1991 1993 1995
FMA8.TRE
0 100 200 300 400
1989 1991 1993 1995
FMA9.SNA
200 400 600
1986 1990 1994
FMA9.GUR
1000 1500 2000 2500
1986 1990 1994
FMA9.BAR
500 1000 2000
1986 1990 1994
FMA9.SPD
0 100 300 500
1986 1990 1994
FMA9.JDO
100 200 300 400
1986 1990 1994
FMA9.SCH
100 200 300
1986 1990 1994
FMA9.SPO
50 100 150
1986 1990 1994
FMA9.TRE
100 200 300 400
1986 1990 1994
SubA.HOK
2 e+04 6 e+04 1 e+05
1992 1996 2000 2004
SubA.LDO
500 700 900 1100
1992 1996 2000 2004
SubA.LIN
20000 26000 32000
1992 1996 2000 2004
SubA.JAV
6000 10000 16000
1992 1996 2000 2004
SubA.GSP
6000 10000 14000
1992 1996 2000 2004
SubA.HAK
1000 3000 5000
1992 1996 2000 2004
SubA.HAKa
2000 4000
1992 1996 2000 2004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10000
15000
1992
1996
2000
2004
SubA.SPD
2000
4000
6000
8000
SubA.CFA
200
600
1000
SubA.CAS
1000
2000
3000
SubA.COL
500
1500
SubA.WWA
500
1500
2500
ELE5
0.6
1.0
1.4
1.8
1990
1995
2000
2005
SCH5
0.7
0.9
1.1
1.3
SCH7
0.8
1.0
1.2
1.4
SCH8
0.6
0.8
1.0
1.2
STA7
0.8
1.0
1.2
1.4
HAK4cpue
1
2
3
4
5
RCO7cpue
1.0
1.5
2.0
2.5
3.0
1990
1994
1998
SNA1cpue
0.80
0.90
1.00
1.10
Chat.SPD
2000
6000
10000

APPENDIX C : Derivation of the association test

Let there be N paired T, YCS values. Divide the T values into bins:

(i) L (low) with m members
(ii) H (high) with n members
(iii) M (medium) with N – m – n members.

Divide the YCS value into bins in the same manner as is done for the T values. Count the number of YCS values that are in the same bin as their paired T value. Let i of them be in the L bin (order is unimportant), and j of them in the H bin (order is unimportant). If the pairing of the T, YCS is random then the probability of obtaining this configuration is

$$\frac{\begin{pmatrix} N-i-j \\ N-m-n \end{pmatrix}\begin{pmatrix} m+n-i-j \\ m-i \end{pmatrix}}{\begin{pmatrix} N \\ m \end{pmatrix}\begin{pmatrix} N-m \\ n \end{pmatrix}} \quad \text{where} \quad \begin{pmatrix} N \\ k \end{pmatrix} = \frac{n!}{(n-k)!k!}$$

Proof

$$\text{P(obtaining configuration)} = \frac{\text{number of ways of obtaining configuration}}{\text{number of ways of putting N YCS into 3 bins}} = \frac{A}{B}$$

Firstly, consider the number of ways of obtaining putting the N YCS values into 3 bins (where the order in each bin is unimportant). Starting with the L bin, with m members, the number of possible ways of putting N objects into it is

$$\begin{pmatrix} N \\ m \end{pmatrix}$$

This leaves N – m YCS values to put into the M bin, which can take N – m – n members, and the number of ways this can be done is

$$\begin{pmatrix} N-m \\ N-m-n \end{pmatrix}$$

The remaining n YCS values can be put only one way (where order is not important) into the H bin with n members. So the number of ways of putting N YCS values into 3 bins is

$$B = \begin{pmatrix} N \\ m \end{pmatrix}\begin{pmatrix} N-m \\ N-m-n \end{pmatrix} = \begin{pmatrix} N \\ m \end{pmatrix}\begin{pmatrix} N-m \\ N-n \end{pmatrix}$$

Now consider the number of ways of obtaining the configuration where for the YCS values, i of them are in the L bin (order is unimportant), and j of them in the H bin (order is unimportant). If there are i objects in the L bin and j in the H bin then there are N – i – j other YCS values to be placed in the bins. For the M bin, with N – m – n members the number of ways this can be done is

$$\binom{N-i-j}{N-m-n}$$

This leaves m + n – i – j YCS values to be placed in the L and H bins, with m – i in the L bin and n – j in the H bin. The number of ways that these can be placed in the left bin is

$$\binom{m-i+n-j}{m-i}$$

The remaining n – j values can be placed in only one way into the H bin (with n – j remaining places to fill), so the number of ways of obtaining the configuration is

$$A=\binom{N-i-j}{N-m-n}\binom{m-i+n-j}{m-i}$$

Taking the ratio A/B gives the required result.